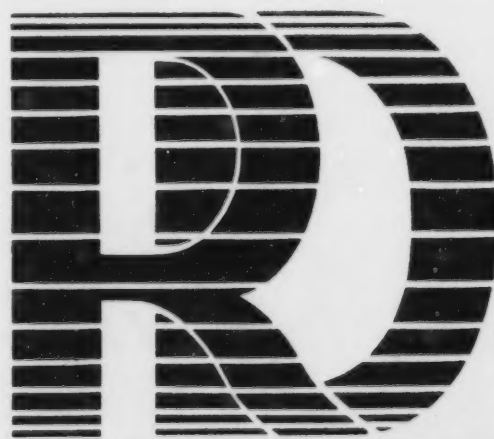
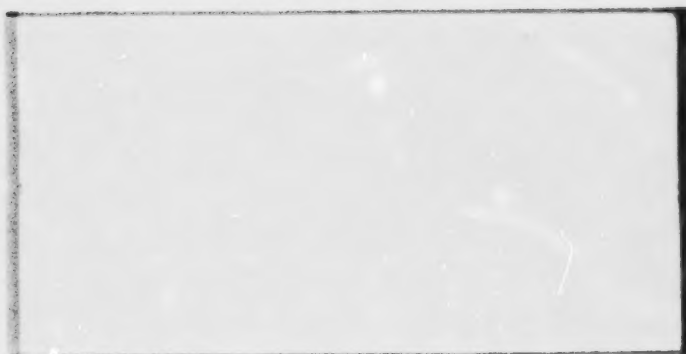




Ontario Hydro



RESEARCH DIVISION

To



ontario hydro
research division

**VIDEO DISPLAY UNITS -
CHARACTERIZATION OF ELECTRIC
AND MAGNETIC FIELDS**

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800 Kipling Avenue, Toronto, Ontario M8Z 5S4

Dear Sir/Madam,

In 1982, in response to concerns raised by office staff, the Health and Safety Division of Ontario Hydro initiated a broadly based study of possible video display terminal health hazards. The objective of the study is to ensure that Ontario Hydro personnel are not placed at risk due to their occupational use of these office machines.

As part of this program, the Research Division was asked to investigate the electric and magnetic fields produced by video display units at Ontario Hydro work-stations. The work is described in the following four Research Division Reports:

- 1) **82-528-K:** Characteristics of Low-Frequency Electrostatic and Electromagnetic Fields Produced by Video Display Terminals.
- 2) **83-503-K:** Analysis of Operator Exposure to Electric Fields From Video Display Units.
- 3) **83-504-K:** Characterization of Low Frequency Magnetic Fields Produced by Video Display Units.
- 4) **84-74-K:** Survey of Electric and Magnetic Fields at Ontario Hydro VDU Work Stations.

There has been considerable demand for these reports. Accordingly, we have bound them together for ease of distribution in this booklet, which is made available to you with the compliments of Ontario Hydro.

Should you require more information or reports concerning the Ontario Hydro VDU study, please contact the Project Manager:

Mr. M.L. Walsh
Safety Services Department
Ontario Hydro
757 MacKay Road
Pickering, Ontario, Canada, L1V 2R5
Telephone: 416-683-7516, Ext 251

A handwritten signature in dark ink, appearing to read "A.F. Baljet".

A.F. Baljet
Manager
Electrical Research Department
Research Division

April 10, 1984





**ontario hydro
research division**

To Mr. F.J. Kee
Director of Research

**CHARACTERISTICS OF LOW FREQUENCY
ELECTROSTATIC AND ELECTROMAGNETIC
FIELDS PRODUCED BY VIDEO DISPLAY TERMINALS**

S.M. Harvey

As part of a preliminary study of health hazards from video display terminals, operator exposure to low-frequency electric fields has been measured. Special equipment designed to cover the frequency range from dc to 10 MHz was used. No fields presently thought to be directly related to health effects were found.

INTRODUCTION

As part of an interdivisional program designed to ensure hazard-free video display terminal work stations, a preliminary study of the low-frequency (0 to 10 MHz) electrostatic and electromagnetic fields produced by a variety of terminals has been made. The study differs from most studies of this type in that it attempts to measure the actual fields to which an operator would be exposed while seated at the keyboard of the instrument, and in that the frequency coverage extends to dc.

Because this is the first Research report on this topic, a detailed description of the techniques and findings is given. Some of the material has been placed in appendices to avoid an overly long report.

BACKGROUND

Since the widespread adoption of the video display terminal (VDT) as a key component of office equipment, there have been

job	740616-424-900	file	817.22	date	December 16, 1982	report no.	82-528-K
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numerous reports of physiological effects experienced by the VDT operators. Reported effects have ranged from fatigue to fetal deformity or miscarriage.

Many studies have been made to try to find a mechanism by which the VDT could cause the reported physiological problems, but so far no specific link has been identified. Ergonomic factors continue to be investigated, but chemical agents, ionizing radiation (X-rays), and high-frequency electromagnetic radiation (including microwaves) appear to have been virtually eliminated as causative factors.

In a recent report, Health and Safety Division pointed out that low-frequency electromagnetic fields from the terminals had not been investigated in spite of several studies which suggested a measurable biological effect from low-frequency fields, particularly of the pulsed variety. It was therefore decided to investigate low-frequency fields as part of a larger program aimed at providing hazard-free VDT work stations.

It is important at this point to make a distinction between low-frequency fields and high-frequency fields. High-frequency fields (for lack of a better definition these will be taken to be fields oscillating at more than 10 MHz) are largely radiative, ie there is an outward flow of energy from the source. Health effects are associated with accumulative absorption of this energy by the body tissues. Most occupational health and safety standards are drafted to limit energy absorption to safe levels by restricting either the field levels or the duration of the exposure.

Low-frequency fields are largely non-radiative and are not significantly absorbed by body tissue. No health effects have been proven at the levels normally associated with occupational exposure. However, recent experiments have raised the possibility of an interaction with the nervous system at moderate field strengths. Pulsed fields with a repetition rate between 15 and 30 Hz are presently under suspicion.

Existing standards, even when arbitrarily extended to the low-frequency region, offer no guidelines on the measurement of occupational exposure to these very low-frequency fields. As techniques developed for radiative fields are clearly inappropriate, new methods are needed.

BASIS OF THE MEASUREMENT METHOD

The problem in the present study is to measure the low-frequency fields that will exist at a person's body when the person is located close to a small device with both a static and a varying charge distribution.

According to the laws of electrostatics, a field exists between any two surfaces that are at different potentials, the relevant surfaces in the present study being the ventral skin or clothing surface of the operator and any portion of the VDT carrying a static charge. For two infinite conducting plane parallel surfaces, a uniform field exists having a value of 1 V/cm if the surfaces are 1 cm apart with a potential difference of 1 V. For other surfaces, the field will be non-uniform and will depend on the shape, conductivity and extent of the surfaces as well as on their separation and potential difference.

Electrostatics can be applied to slowly varying electric fields over short ranges and remain a good approximation over distances of the order of 1 m for fields varying at a rate of several MHz. Therefore, a measurement system which is based on electrostatics rather than radiation theory should be capable of covering the low-frequency range (less than 10 MHz) electric fields at least for equipment which is close enough to be operated by hand.

It is difficult to measure arbitrary electrostatic fields as these can vary quite rapidly over small distances and are easily perturbed by the measuring equipment. These problems can be removed by measuring the field at the surface of a flat conducting plate which is maintained at a known potential, ie ground potential. At such a surface the field is oriented at right angles to the surface and is relatively uniform, allowing unperturbed measurement.

Under certain conditions, the electrically grounded flat plate will provide a reasonable simulation of the human body. These include:

- similar surface area exposed to the source,
- similar orientation relative to the source,
- moderately conductive and uncharged bodies.

Human bodies may carry an electrical charge, potentials of up to ± 2 kV relative to ground having been observed. However the charge is likely to be small in the anti-static environment of an "electronic office", and in any event would likely redistribute itself so as to minimize any internal fields. These factors suggest that a properly designed grounded plate may provide a "worst case" measurement of the fields to which an operator would be exposed.

In the present work, a flat metal plate is used to simulate the frontal surface of the VDT operator. There is no doubt that a

better simulation could be used. However the additional complications can not be justified at this stage of the program.

MEASURING EQUIPMENT

Most of the measurements in this study were made at the surface of a grounded sheet of copper foil 30 cm (1 ft) wide and 122 cm (4 ft) high located in a vertical position on the floor at a horizontal distance of 30 cm (1 ft) from the centre of the CRT display screen and directly in front of it. The frontal area of the sheet is similar to that of a seated operator and the location represents a "closest approach" position as shown in Figure 1. The field sensor is located on the copper sheet level with the CRT screen.

The field sensor consists of a circular copper plate 11.5 cm in diameter located 1 cm from the copper foil and insulated from it. The plate and 2 m of RG58/U coax form a capacitive divider whose voltage is measured with appropriate equipment. Using available equipment, the system response extends from 0.005 Hz to about 10 MHz in two overlapping ranges and is extended to dc by manually "chopping" the field. Full details of the measurement system and calibration procedures can be found in Appendix A.

For convenience in finding field maxima and minima, a small field probe was also used. The small probe has an 11 cm square ground plane. Therefore the fields at this surface will not be the same as those measured at the surface of the larger sheet and direct quantitative comparisons are not meaningful.

All measurements were made with the VDT unit placed on a wooden table in a low-background basement room.

UNITS SELECTED FOR TESTS

Four different terminals of varying vintage from three different manufacturers were selected for detailed study. The oldest, date of manufacture unknown, was purchased by the Research Division in 1979. The newest was manufactured in October 1981 and carries a sticker stating compliance with Part 15 of FCC rules for Class A computing device (these rules limit radiated electromagnetic interference). The two newest units could be set to provide an interlaced picture although interlace was not normally used due to an annoying display flicker. All CRT screens had approximately an 18 x 24 cm display area.

FIELD CHARACTERISTICS

All four terminals were found to produce qualitatively similar electric fields. The field characteristics are described below with the range of field parameters indicated in each case, and the results are summarized in Table I. A detailed description of the fields from one unit is given in Appendix B.

1. A dc electrostatic field is produced by the positively charged surface of the CRT display screen. The dc field may momentarily exceed 100 V/cm when the terminal is first turned on. After about one half hour of operation the field will lie in the range from 7 V/cm to 70 V/cm depending on the unit tested, an equilibrium value presumably being reached when the charge leakage from the screen just balances the electron beam current. The newest terminals do not necessarily have the lowest fields.

The dc field is strongest directly in front of the CRT display screen and decreases quickly with increasing distance, the approximate relation being $E \propto R^{-2.5}$.

2. The dc field is modulated, when a display is present, by the process of writing on the CRT screen. The modulation waveform has a 60 Hz repetition rate and can be quite complex, depending on the display format. For a fixed format, the modulation amplitude increases with the brightness of the display.

A half-screen display produces the maximum modulation amplitude. The maximum modulation amplitude ranges from a high of 1.1 V/cm rms for one of the older units at maximum brightness to about 0.3 V/cm rms for the two newest units. Detectable harmonics extend up to about 1 MHz, although 20 kHz is a more practical measurement limit.

Modulation components below a frequency of 60 Hz are normally absent at the limit of sensitivity, but could be introduced by selecting special displays; for example, interlace (30 Hz), or a blinking cursor on a clear screen (0.5 to 2 Hz). When present, the amplitude of these field components is 10 mV/cm rms or less.

It should be noted that the electrostatic field will also be modulated by the operator's movements, ie while making keyboard entries. However, this effect was not studied.

3. A pulsed field with a repetition rate of about 16 kHz (the line scan frequency) is produced by the high-voltage fly-back circuitry and is present at all times when the unit is

turned on. The pulsed field is strongest at the back or side of the terminal near the flyback transformer and relatively quite weak at the front where it is shielded by the chassis and CRT. The back-of-set fields fall to the same level as experienced by the front-of-set operator at a distance of 120 cm (4 ft) or less.

The zero to peak pulsed field amplitude at the front of the terminal ranges from a high of 1.7 V/cm for one of the older machines to a low of 0.2 V/cm for one of the newer ones. The rise time of the pulse is typically 2 to 4 μ s. RMS amplitudes of the fundamental are about 10% of the peak pulse amplitude and harmonics can be measured up to 1 MHz.

4. Logic circuits produce variable low-level pulsed fields over a wide frequency range. Component amplitudes are less than 1 mV/cm rms, but can be somewhat higher close to the keyboard. These pulsed fields are largely absent when the terminal is in a "quiescent" state.

TABLE I

SUMMARY OF ELECTRIC FIELDS MEASURED AT A
GROUNDED CONDUCTING SURFACE 30 cm FROM THE CRT SCREEN UNITS -
VOLTS PER CENTIMETER (V/cm)

	VDT Unit			
	1	2	3	4
dc fields, about half hour after turn-on	60	7	70	60
maximum modulation amplitude, rms (normal brightness)	0.60	0.65	0.25	0.30
16 kHz pulse peak amplitude	0.55	1.7	0.23	0.19
approximate rms amplitude	0.1	0.3	0.05	0.03
other fields, rms amplitude	<0.001	<0.001	<0.001	<0.001

EFFECT OF ADDED SHIELDING

- (a) In order to test the effect of case shielding the plastic case of the oldest unit was lined with copper foil which was grounded to the VDT chassis via the hold-down screws.

The 16 kHz pulse amplitude from the flyback circuit was reduced by a factor of six in front of the set. At the back of the set the pulse amplitude was reduced by a factor of 20. Other field components were not significantly affected.

- (b) In order to test the effect of transparent conductive CRT screen covers, a grounded open wire mesh was placed in front of the CRT display screen.

The amplitude of the modulated dc field was reduced by a factor of 20. Flyback pulsed fields were reduced slightly at the front of the set, but no change was observed at the back.

COMPARISON WITH A COLOUR TV RECEIVER

For comparison purposes, electric fields produced by a 20-inch colour TV receiver of recent manufacture were measured. The results were as follows:

- dc fields were very weak, being consistently less than 5 V/cm. This may be a result of the internal mask used in the set tested;
- the 60 Hz repetition rate modulation component was very strong. A person sitting 120 cm (4 ft) from the TV receiver would be exposed to the same modulation amplitude as a person sitting 30 cm (1 ft) from a typical VDT. This strong modulation field should not be surprising in view of the fact that TV pictures are usually much brighter than VDT displays;
- the 16 kHz pulse fields were near the high end of the amplitude range observed from the terminals.

REMARKS CONCERNING POSSIBLE HEALTH EFFECTS

The measurements made in this study show that no VDT operator will be exposed to low-frequency electric fields in excess of any known occupational health and safety guideline. Persons working within 30 cm (1 ft) of the back of some sets could receive an exposure in excess of the most restrictive standards, but as it is difficult to operate a keyboard from this position, the risk will be largely confined to service personnel.

No evidence for pulsed fields between 15 and 30 Hz was found. A weak, low-frequency component at 30 Hz is produced by interlace but the interlace option, if provided, is seldom used.

DC fields can be of substantial magnitude. Although there are no known direct health effects from such fields, an indirect effect from atmospheric positive ions has been suggested.

CONCLUSIONS

Low-frequency electric fields produced by a selection of VDT's have been measured. The measuring equipment has been designed to yield values representing the partial body exposure that would be experienced by an operator seated at the keyboard at a distance of 30 cm (1 ft) from the display screen.

The fields are composed mainly of two components:

1. A modulated dc field produced by the CRT. During normal operation the dc field may have a magnitude of between 7 and 70 V/cm depending on the make of terminal. The modulation has a distorted 60 Hz waveform and an rms amplitude between 0.25 and 0.60 V/cm.
2. A pulsed field with a pulse repetition rate of approximately 16 kHz. The peak pulse amplitude is between 0.2 and 1.7 V/cm. RMS amplitudes are estimated to be between 0.03 and 0.3 V/cm.

The fields are characteristic of raster-scan CRT devices, including television sets.

In the frequency range from dc to 10 MHz, no fields having characteristics presently known or suspected of being detrimental to human health were found. In the event that health or safety concern are raised, the fields are easily reduced by adding local shielding to the equipment case.

Service personnel may be exposed to fields in excess of some standards at the rear of the set. In this regard, case shielding would be of little benefit as servicing would require removal of the case.

Approved:

A. F. Baljet

A.F. Baljet
Manager
Electrical Research Dept

SMH
SMH:km

Submitted:

S.M. Harvey

S.M. Harvey
Engineer - Physicist
Science Section

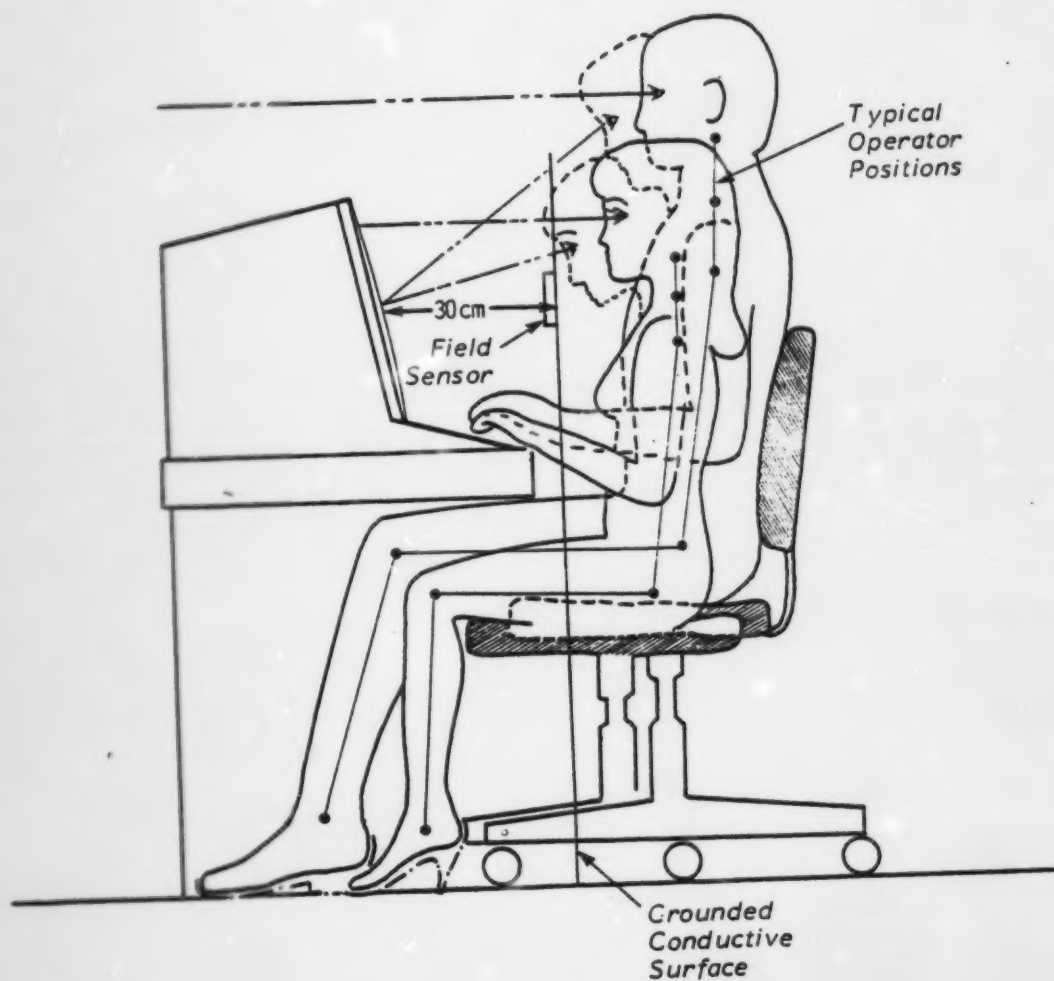


FIGURE 1
FIELD MEASUREMENT
GEOMETRY AND OPERATOR POSITION

APPENDIX A

FIELD MEASURING EQUIPMENT AND CALIBRATION

1. SENSOR GEOMETRY

The field sensor is designed to provide an output voltage proportional to the electric field normal to the surface of a flat conducting plate at ground potential.

The sensor consists of a 1 mm thick circular copper plate of 11.5 cm diameter mounted parallel to the grounded plate with an air gap of 1 cm. The circular plate is connected to the centre pin of a BNC connector attached to the back side of the grounded plate. A 2 m length of RG58/U coax completes the sensor geometry. The sensor is shown in Figure A1.

2. SENSOR EQUIVALENT CIRCUIT

The sensor equivalent circuit is shown in Figure A2. When connected to a voltage measuring device with input resistance R_L and input capacitance C_L , the frequency response is as shown in Figure A3.

3. VOLTAGE MEASURING EQUIPMENT

- (a) For very low frequency analysis, the sensor is connected to a Keithley Instruments Model 610B analog electrometer. According to the instrument manual, the 610B has an input impedance of greater than 10^{14} ohms shunted by 22 pf.

Voltages which do not change within the analog meter time constant can be read directly on this instrument. For faster changes, a low impedance analog output is available for display on an oscilloscope or spectrum analyser. The bandwidth of the output circuitry is several kHz.

- (b) For higher-frequency analysis, the sensor is connected to a Tektronix 465 oscilloscope with a 100 MHz bandwidth and an input impedance of 10^6 ohms shunted by 20 pf. From Section 2, it is seen that the sensitivity will be identical, only the low-frequency limit being changed by the lower input resistance. The 465 also has a low impedance analog output which may be connected to a spectrum analyser.

(c) The spectrum analysers used for measuring low-level voltages in the presence of large signals were:

- (i) HP3582A - Frequency Range 0 to 25 kHz
- Input Impedance 1 M Ω
- (ii) HP8568A - Frequency Range 100 Hz to 1.5 GHz
- Input Impedance 50 Ω

The dynamic range of these instruments is of the order of 80 dB.

4. SENSOR CALIBRATION

Calibration was performed by exposing the sensor to a known uniform field produced by a 30 cm x 50 cm plate located 10 cm from the grounded plate and directly over the sensor (see Figure A1). The field in V/cm produced by this arrangement is to sufficient accuracy equal to 1/10 of the voltage applied to the calibration plate up to a frequency of above 1 MHz.

A reasonable upper limit for the frequency response of the sensor is the point at which the length of the coax cable is 10% of the signal wavelength. This limit occurs at 10 MHz for a 2 m cable.

The lower frequency limit with the sensor connected to the 610B electrometer was determined by recording the system response to a step-function dc field.

A plot of the calibration data is shown in Figure A4.

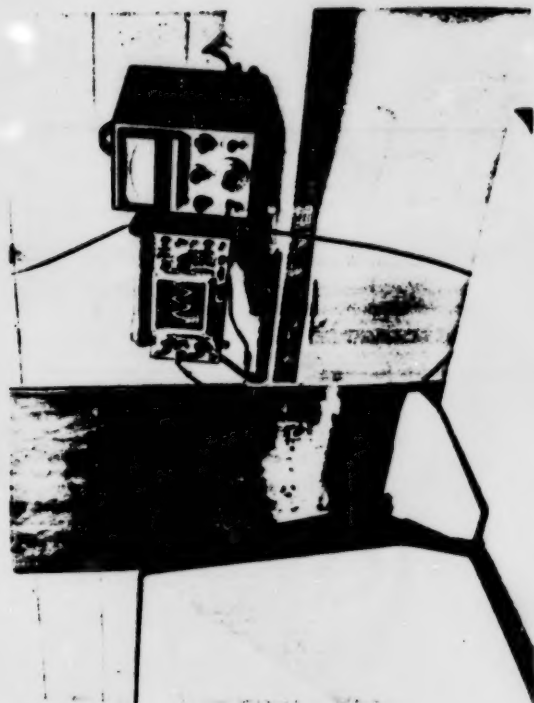
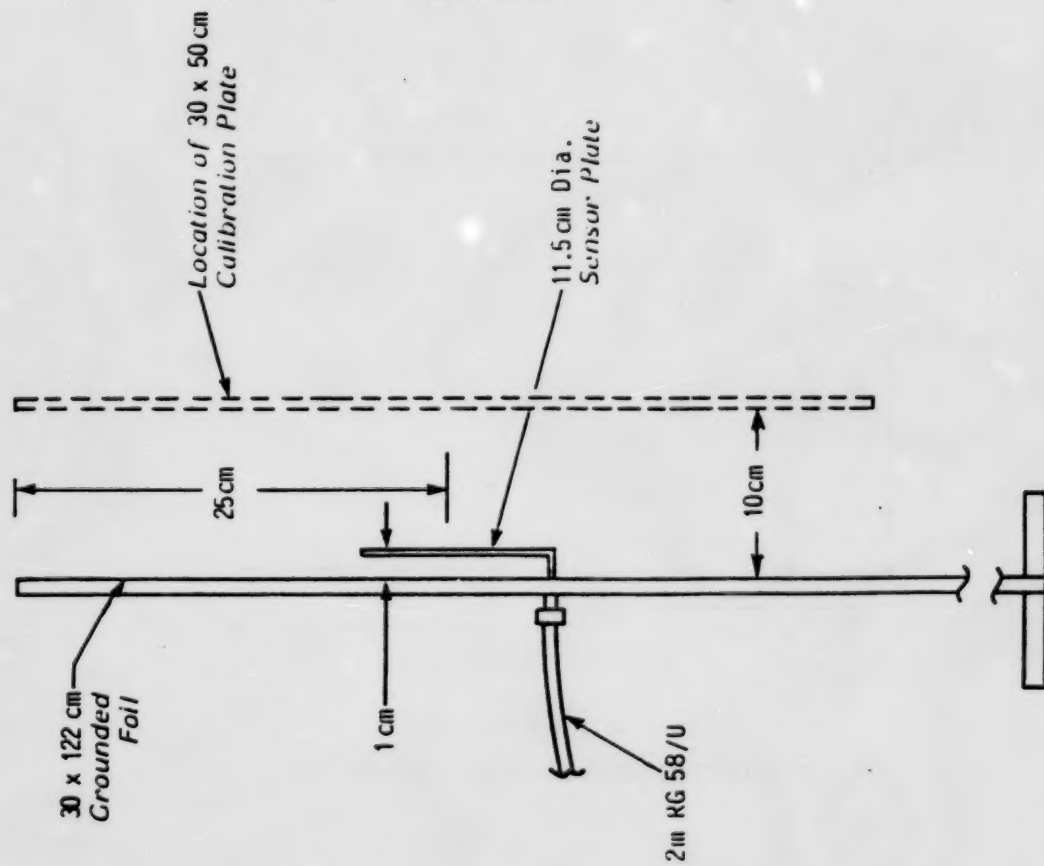


FIGURE A1
E-FIELD SENSOR CONFIGURATION

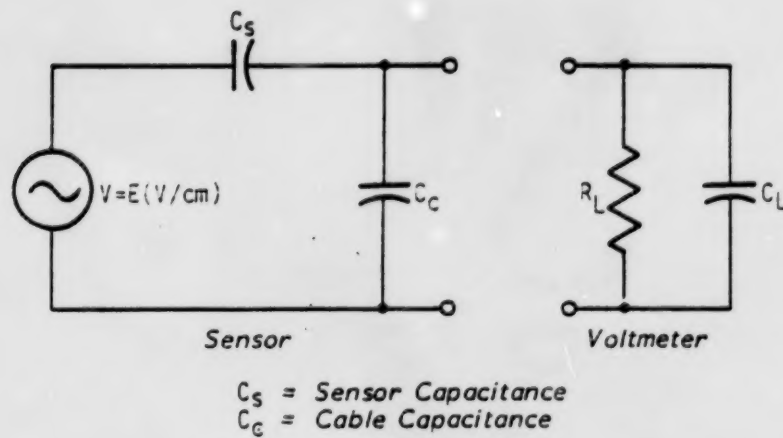


FIGURE A2
SENSOR EQUIVALENT CIRCUIT

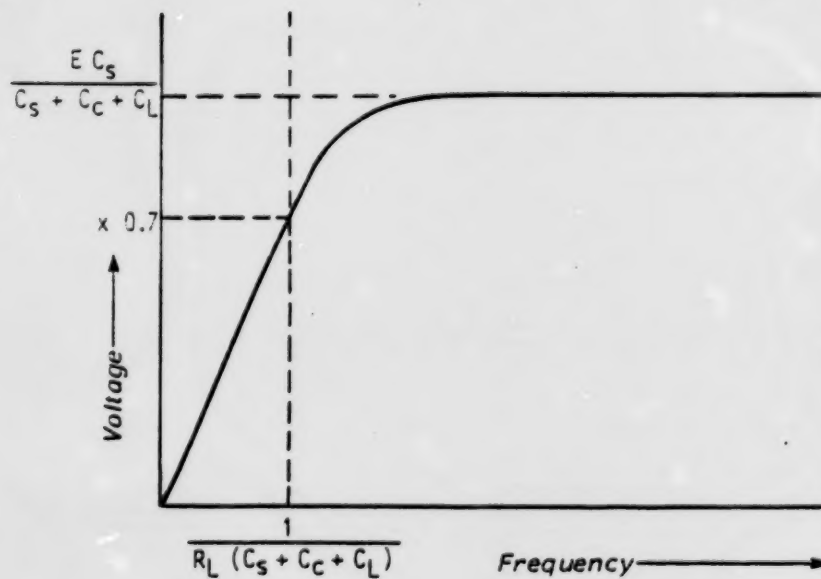


FIGURE A3
THEORETICAL FREQUENCY RESPONSE

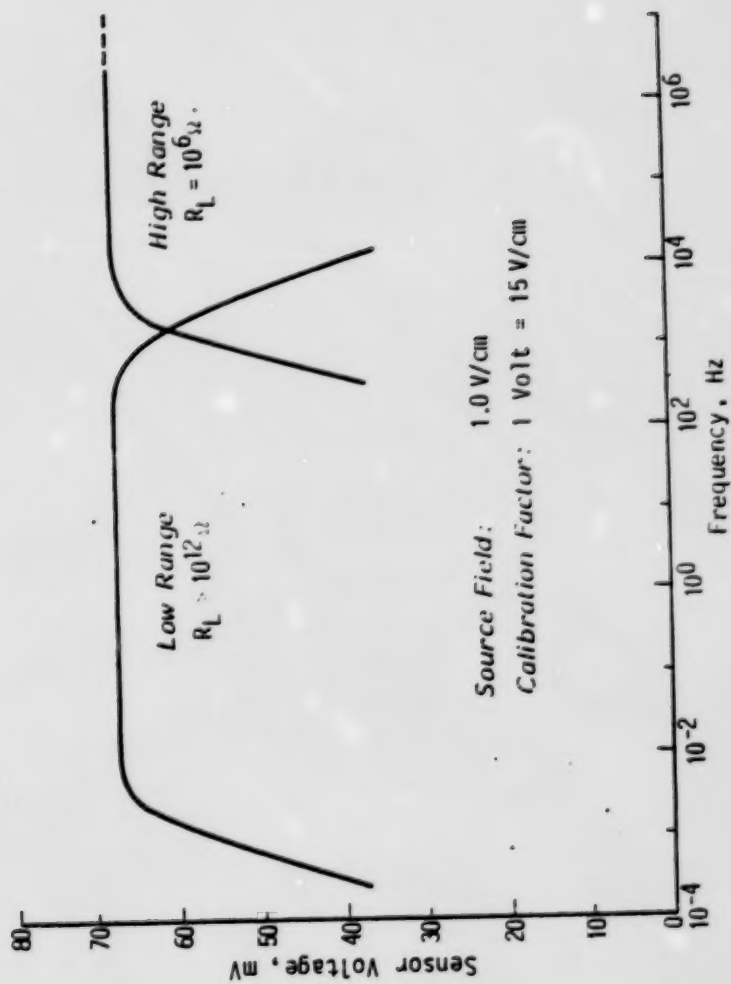


FIGURE A4
E-FIELD SENSOR CALIBRATION DATA

APPENDIX B

DETAILED STUDY OF LOW-FREQUENCY ELECTRIC FIELDS PRODUCED BY A VIDEO DISPLAY TERMINAL

1. DESCRIPTION OF THE TERMINAL

The terminal selected for a detailed study was an early model of limited intelligence. This model has a detachable keyboard and an 18 cm x 24 cm display area. The brightness control is ganged with the off/on switch instead of being preset internally.

A flashing cursor is set automatically on turn on and the unit can be set to write and scroll automatically by taping down one key.

A full display consists of 24 lines of 80 characters each. A full scan consists of 265 lines, 10 lines being used for each line of text, according to a visual count of the repetition rates. The refresh rate is 60 Hz and there appears to be no interlace.

2. METHOD OF MEASUREMENT

For field measurements, the VDT was placed on a wooden table near the centre of a basement room with a low background level of extraneous fields.

The grounded reference plane was located vertically at a horizontal distance of 30 cm (1 ft) from the centre of the CRT screen, such that the field sensor was at the same level as the screen. Previous measurements had shown the CRT generated fields were maximum in the front horizontal plane or slightly above it.

For angular measurements of the pulsed flyback fields, the terminal was mounted so that it could be rotated about a vertical axis through the centre of the unit.

DC fields (ie, those fields which changed slowly in comparison with the time constant of the system) were measured by chopping the field with a grounded metal plate. This could be done quite conveniently by hand.

The results, described below, are divided into the following three categories according to the method of measurement: dc fields, ac fields measured on the low-frequency range, and ac fields measured on the high-frequency range.

3. RESULTS

3.1 DC Fields

DC fields depended on the previous operating history of the unit and could be changed, ie by touching the CRT screen to bleed off charge. Therefore, a standardized procedure was adopted. First, the terminal was allowed to run for an extended period of time. Then it was turned off and the field was measured for 30 minutes. The residual charge was removed as well as possible by touching the screen and the terminal was then turned on again with a display on the screen. Following this the field was recorded for another 30 minutes.

The results of these measurements are shown in Figure B1.

3.2 AC FIELDS BELOW 2 kHz

AC fields with frequencies below 2 kHz were measured with the 610B electrometer in circuit. After some experimentation it was found that these fields consist almost entirely of dc field modulation components whose amplitudes are directly related to the brightness of the CRT display.

3.2.1 Real Time Displays

Figure B2 shows three photographs of low-frequency field waveforms. Picture (a) shows the modulation produced by a blinking cursor on a clear screen against a background of 60 Hz fields from the external environment. The rms field modulation amplitude is about 10 mV/cm. Pictures (b) and (c) show the complex 60 Hz waveform produced by half-screen and full-screen displays. Each of the small oscillations represents the scanning of one line of text.

The peak-to-peak amplitude in Picture (b) is the largest observed for this terminal. It represents a peak-to-peak modulation of 3.2 V/cm or an rms field amplitude of 1.1 V/cm. At normal brightness, the field is about 50% smaller.

3.2.2 Spectrum Analyser Displays

Figures B3, B4 and B5 show HP3582A spectrum analyser displays of the real-time signals with frequency ranges of 0-25 Hz, 0-100 Hz and 0-2.5 kHz respectively. In addition to confirming the real time data, these pictures show the harmonic content of the field modulation.

Notes: (i) Because the brightness control is ganged to the off/on switch, it can not be assumed that all records were obtained at the same brightness.

- (ii) Great care must be taken while recording the lowest frequencies that spurious modulation is not produced by people walking near the terminal.

3.3 AC Fields Above 2 kHz

AC fields above 2 kHz were measured with the 465 oscilloscope in circuit. These fields were found to consist almost exclusively of higher harmonics of the dc modulation field and a pulsed field with a repetition rate of 15.9 kHz which originated with the high-voltage flyback circuitry.

3.3.1 Real Time Displays

Figure B6 shows the waveform of the pulsed field. The zero to peak amplitude of the pulsed field is independent of the CRT display parameters, but varies greatly with the sensor location. Figure B7 shows a polar plot of the zero to peak field amplitude obtained by rotating the VDT around a vertical axis. This rotation takes the sensor quite close to the case and a more realistic representation, the locus of constant field, is shown in Figure B8.

The pulsed field is strongest near the corner of the chassis containing the flyback transformer. It is shielded at the front and under the table by the chassis and CRT. Therefore, a person sitting 120 cm (4 ft) from the rear corner will experience the same field amplitude as a person sitting 30 cm (1 ft) from the front of the CRT.

In order to test the effect of internal shielding, the inside of the plastic VDT case (top, back and sides) was lined with copper foil which was grounded to the chassis via the case hold-down screws. A polar plot of the field strength from the shielded terminal is also shown in Figure B7. The shielding had little effect on fields from other sources.

3.3.2 Spectrum Analyser Displays

In order to reduce the amplitude of the pulsed fields and therefore prevent overloading of the spectrum analyser while looking for weak fields all spectral measurements were made with the case shielding in place.

Figures B9 and B10 show spectrum analyser displays for the frequency ranges 0-25 kHz and 0-100 kHz respectively. Figure B11 shows displays for the ranges 0-1 MHz and 0-10 MHz.

Figures B9 to B11 illustrate the following features of the VDT fields:

- (a) A virtually clean pulse spectrum under clear screen conditions.
- (b) The rapid fall-off of dc field modulation harmonics with increasing frequency.
- (c) The absence of significant field components in the 1-10 MHz range.
- (d) The presence of low-level broadband pulsed fields in the automatic writing mode, and some low-level cw fields, ie at 21.5 kHz and 88 kHz.

Some of the higher frequency components were examined at maximum resolution (10 Hz) in a search for sidebands produced by modulation in the range below 60 Hz. No such sidebands were found.

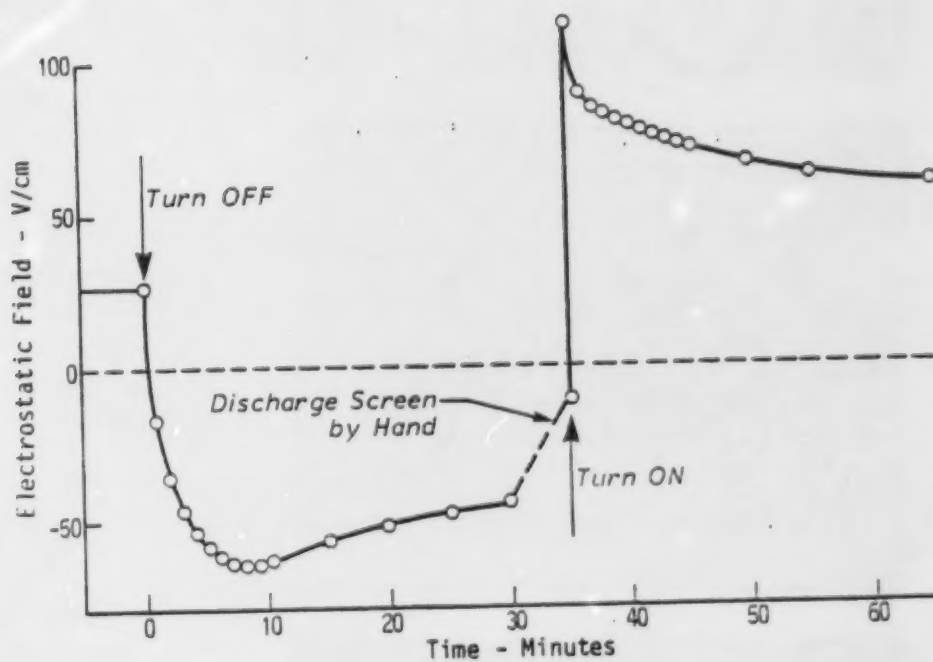
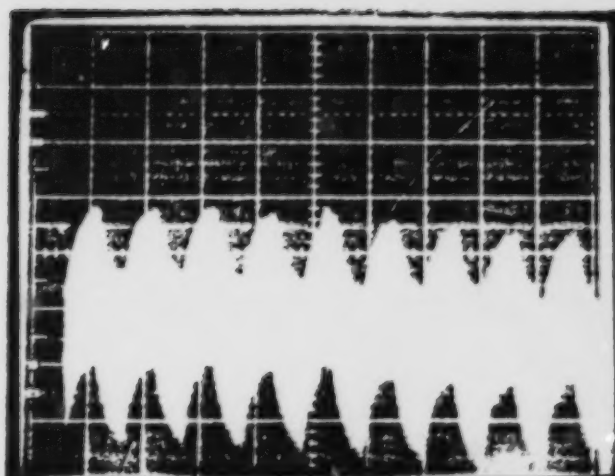


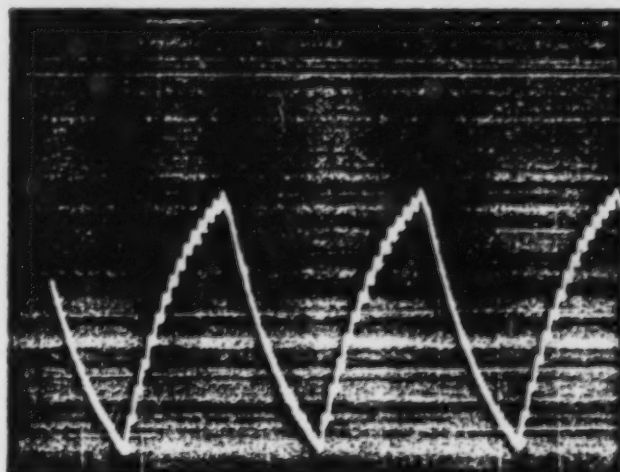
FIGURE B1
VDT ELECTROSTATIC FIELD



a) BLINKING CURSOR ON A CLEAR SCREEN

*Normal Brightness.
The trace is broadened by 60Hz background fields.*

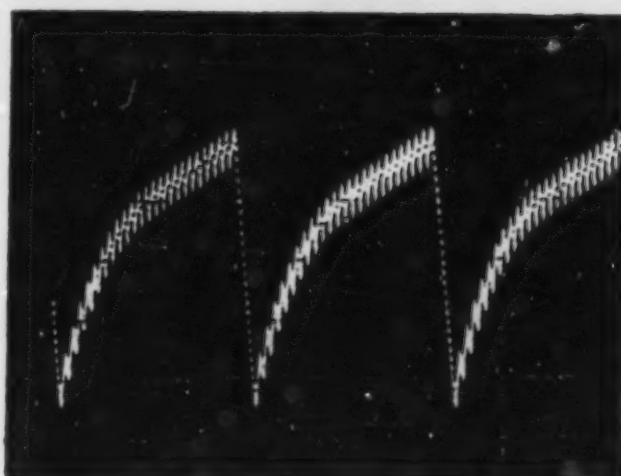
*Vertical Scale: 0.03V/cm/div.
Horizontal Scale: 0.5 s/div.*



b) HALF-SCREEN DISPLAY (FIRST 14 LINES OF TEXT)

Near Maximum Brightness.

*Vertical Scale: 0.75 V/cm/div.
Horizontal Scale: 5 ms/div.*



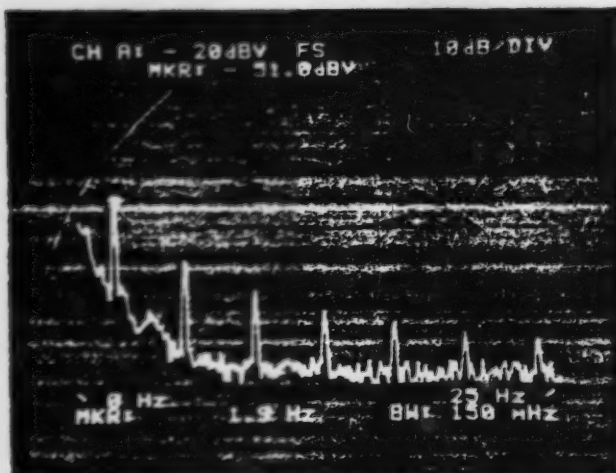
c) FULL SCREEN DISPLAY (24 LINES OF TEXT)

Near Maximum Brightness.

*Vertical Scale: 0.3 V/cm/div.
Horizontal Scale: 5 ms/div.*

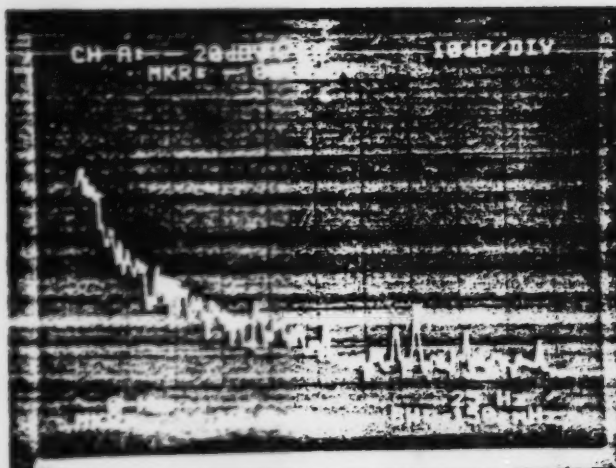
FIGURE B2

LOW FREQUENCY FIELD MODULATION WAVEFORMS



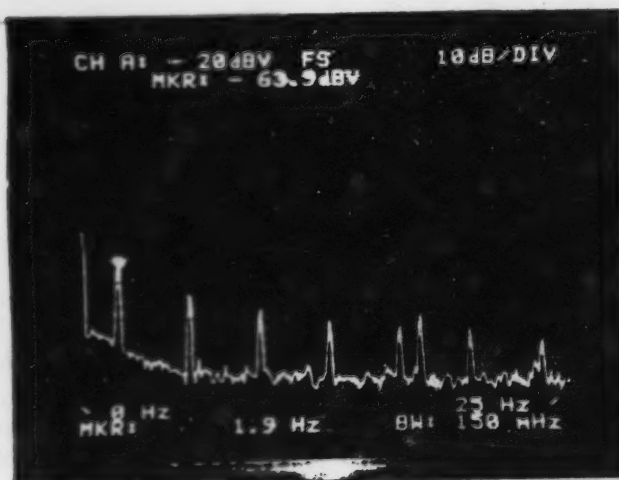
a) BLINKING CURSOR ON A CLEAR SCREEN

The signal has 10dB of pre-amplification. Therefore, the peak at 1.9Hz is -16dBV or 13mv/cm including background.



b) CHARACTER KEY DEPRESSED. VDT IS WRITING AND SCROLLING AT 18 CHARACTERS/SEC.

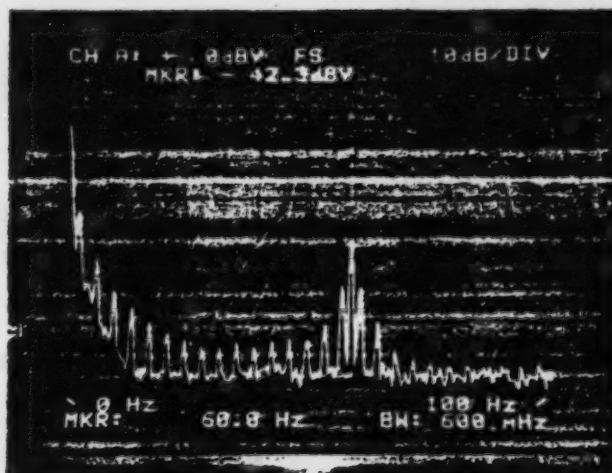
The signal has 10dB of pre-amplification, putting the 18Hz component at -90dBV or 0.5mV/cm rms.



c) BLINKING CURSOR ON A FULL SCREEN

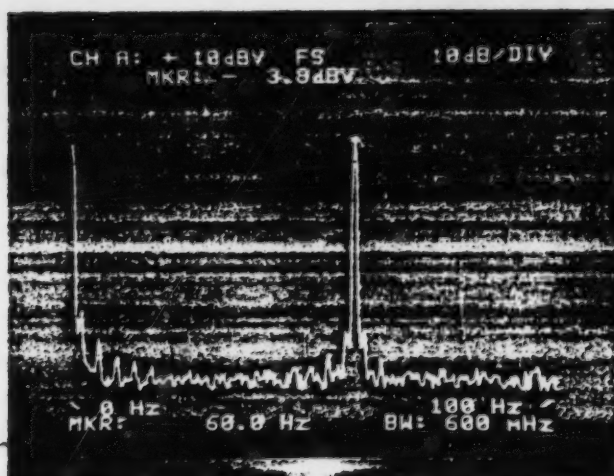
The signal has 10dB of pre-amplification, putting the 1.9Hz component at -74dBV or 3mV/cm rms.

FIGURE B3
SPECTRUM ANALYZER DISPLAYS, 0-25Hz



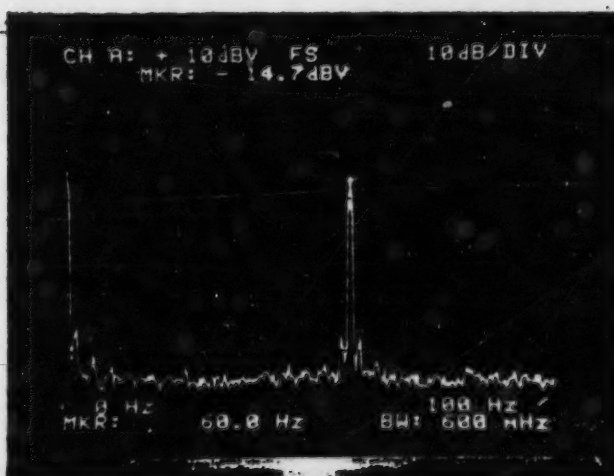
a) BLINKING CURSOR ON A CLEAR SCREEN

Preamplification is 20dB. The 60Hz component is largely due to stray fields from external sources.



b) BLINKING CURSOR ON A HALF-FULL SCREEN

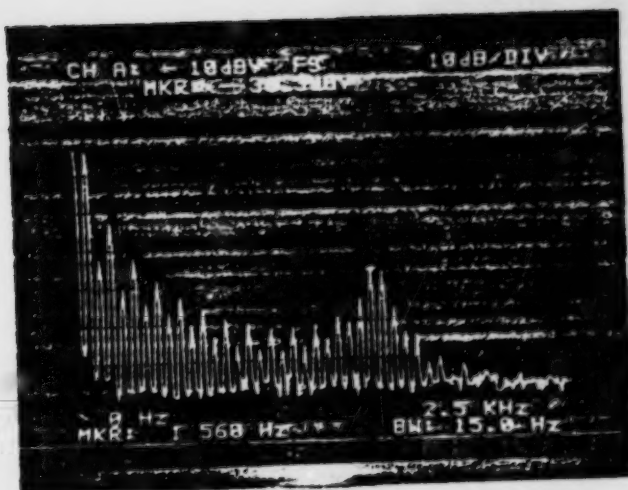
Preamplification is 20dB. The 60Hz component is -23.8dBV or 1.0V/cm rms.



c) BLINKING CURSOR ON A FULL SCREEN

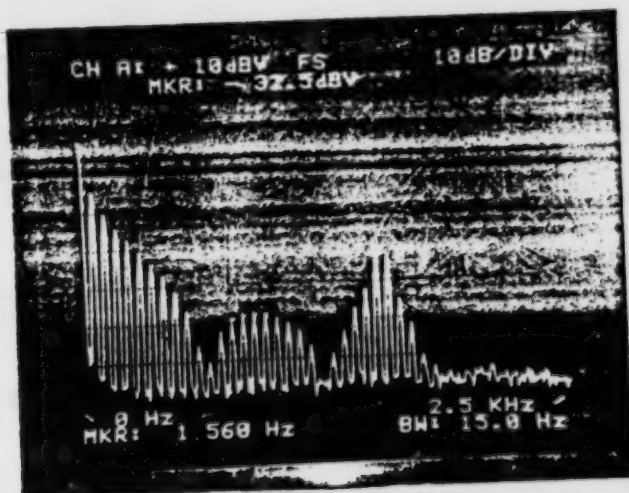
Preamplification is 20dB. The 60Hz component is -34.7dBV or 0.3V/cm rms.

FIGURE B4
SPECTRUM ANALYZER DISPLAYS 0-100Hz



a) SCREEN HALF FULL

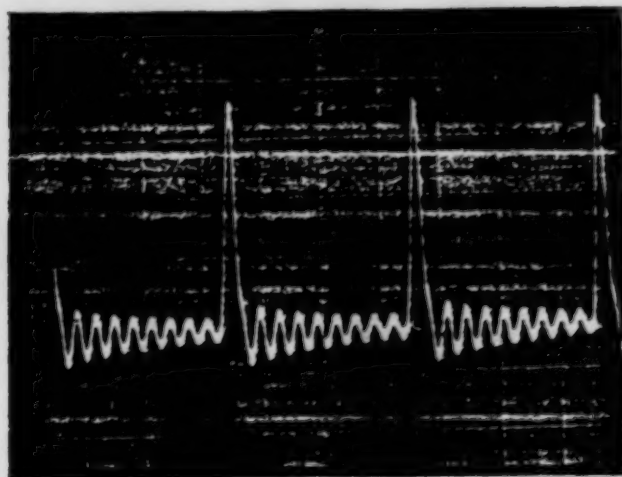
*Preamplification is 20dB.
The subsidiary harmonic
maximum at 1.59 kHz
corresponds to the rate at
which the lines of text are
scanned.*



b) SCREEN FULL

*Preamplification is 20dB.
This photo shows the
dependence of the field
modulation harmonic content
on the display format.*

FIGURE B5
SPECTRUM ANALYZER DISPLAYS 0-2.5 kHz



Horizontal Scale is 20 μ s/div.

FIGURE B6
WAVEFORM OF 15.9 kHz PULSED FIELD

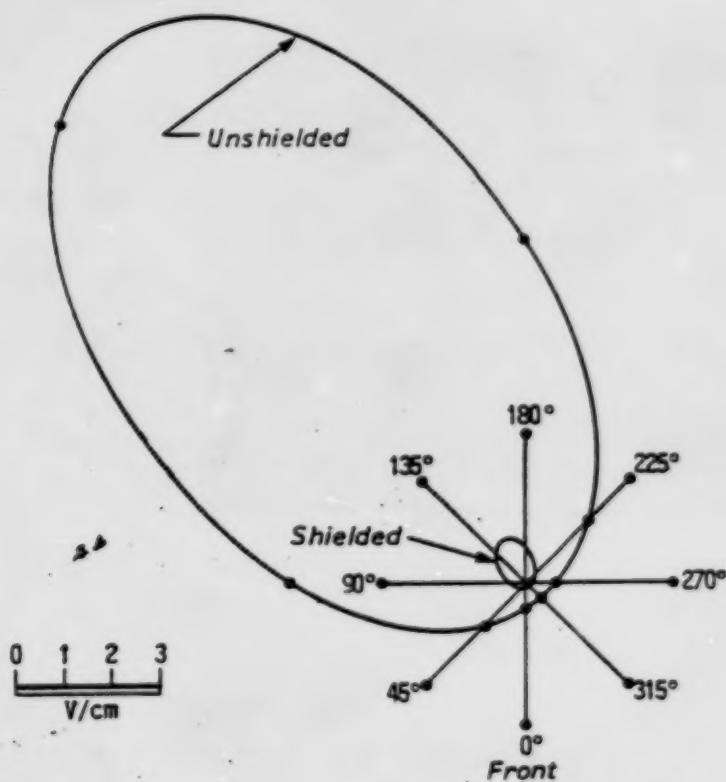


FIGURE B7
POLAR DIAGRAM OF PULSED PEAK FIELD STRENGTHS
IN HORIZONTAL PLANE

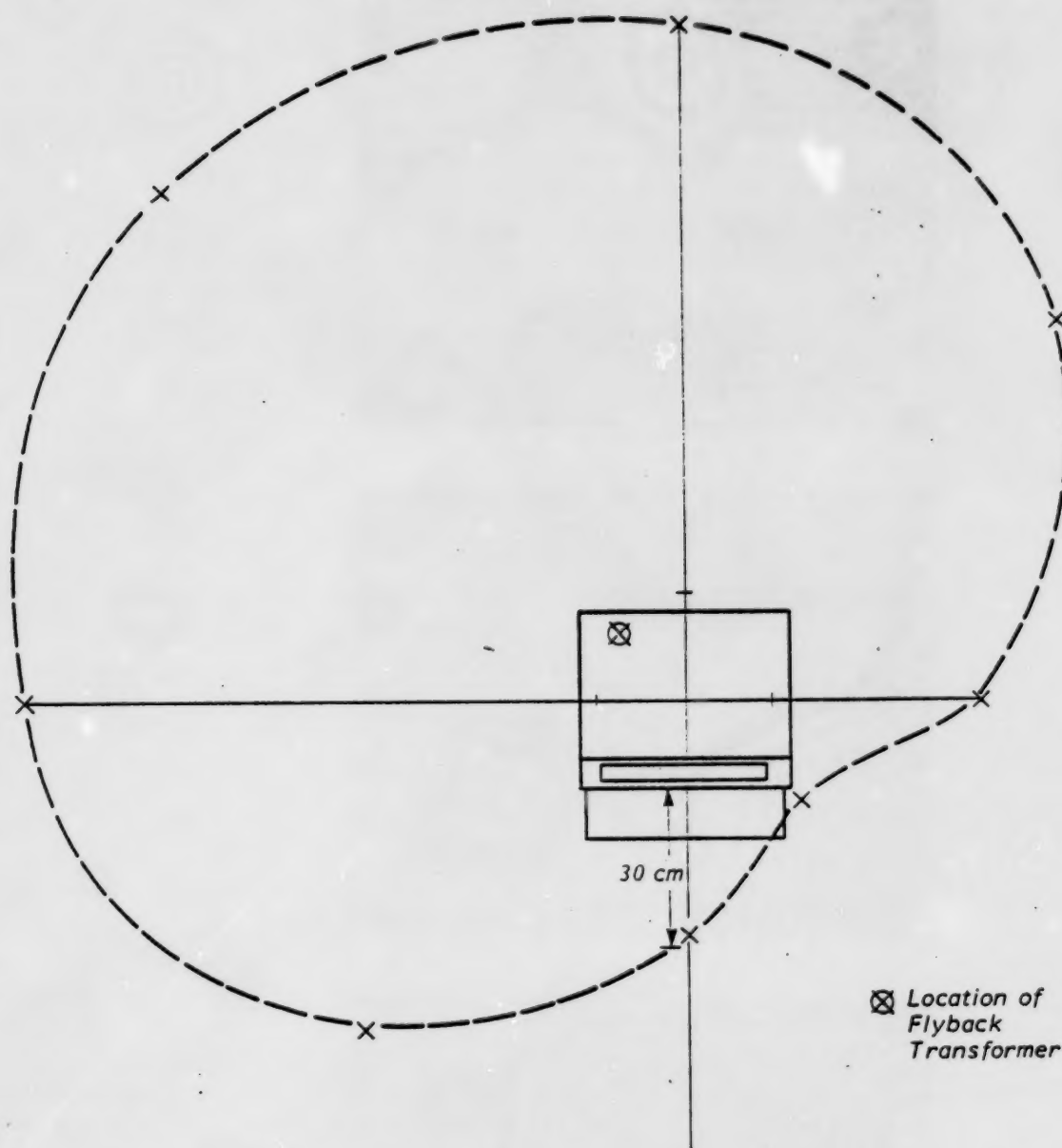
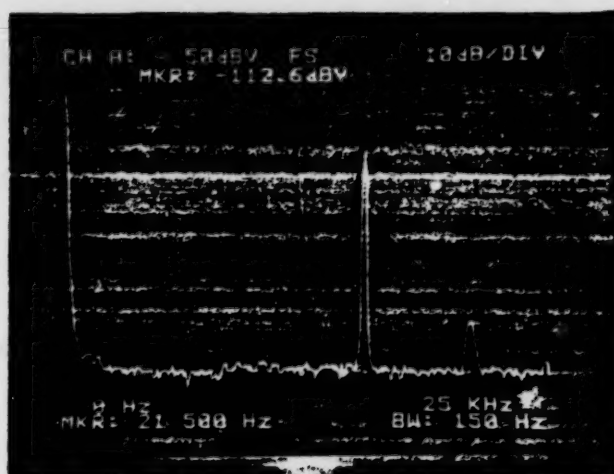


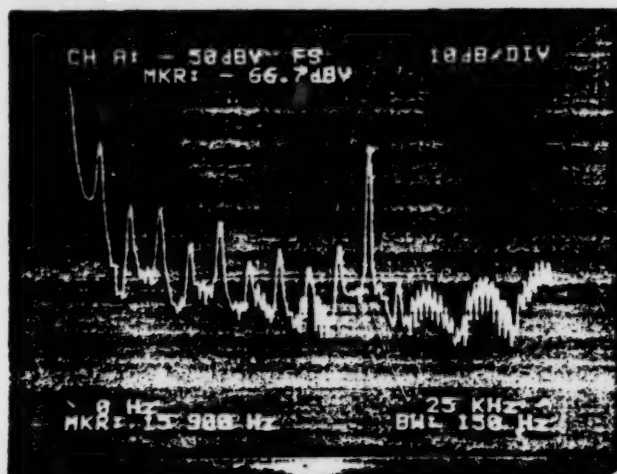
FIGURE B8
LOCUS OF CONSTANT PULSED FIELD
(0.55 V/cm PEAK TO PEAK)

160083-RD



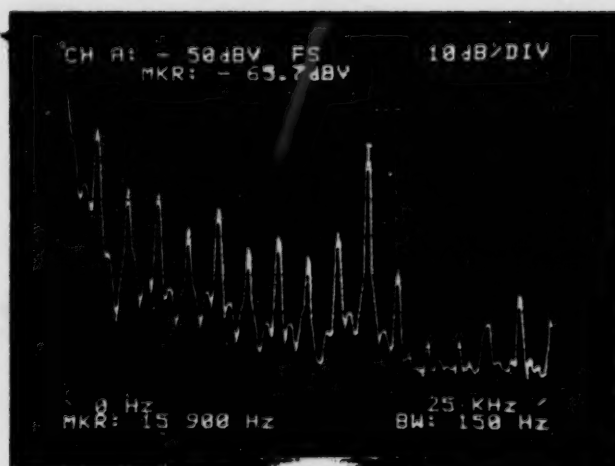
a) BLINKING CURSOR ON A CLEAR SCREEN

Preamplification is 0 dB. The 15.9 kHz fundamental of the pulse field is shown. The 21.5 kHz component is in the $\mu\text{V}/\text{cm}$ range.



b) HALF-SCREEN DISPLAY, KEY DEPRESSED

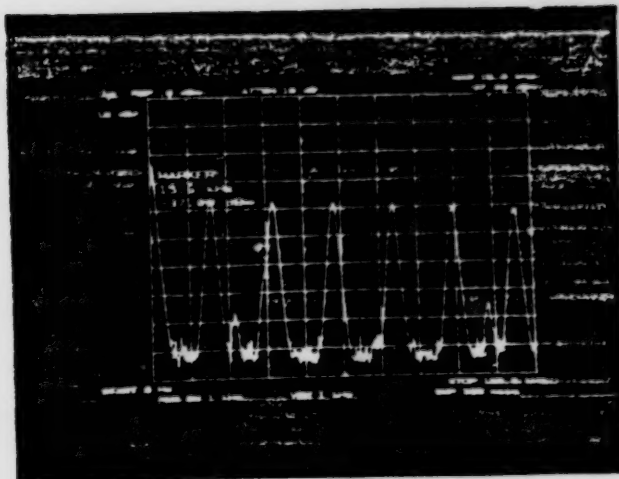
Preamplification is 0 dB. The fine structure disappears when the key is lifted.



c) FULL SCREEN DISPLAY

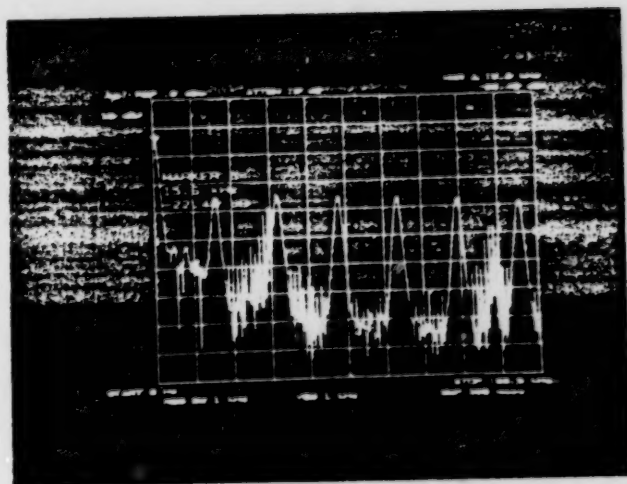
Preamplification is 0 dB. The 60 Hz harmonics of the dc field modulation are not resolved in this picture, only the "envelope" is shown.

FIGURE B9
SPECTRUM ANALYZER DISPLAYS 0-25kHz



a) BLINKING CURSOR ON A CLEAR SCREEN

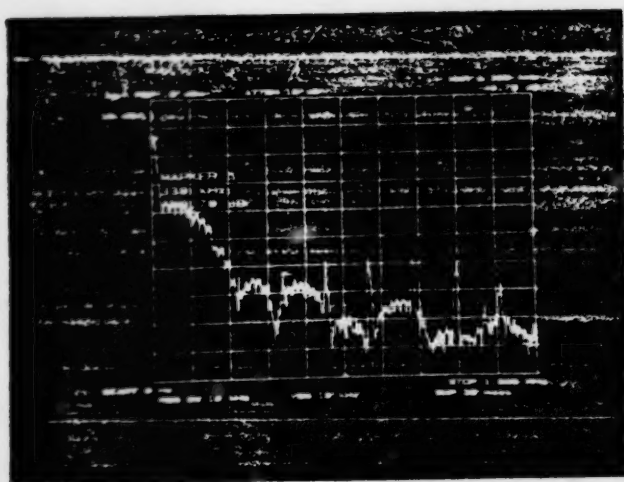
*Preamplification is 16dB.
Harmonics of the 16kHz pulsed
field are shown. The fundamental
is -66dBV or 7.5mV/cm rms.*



b) HALF-SCREEN DISPLAY, KEY DEPRESSED

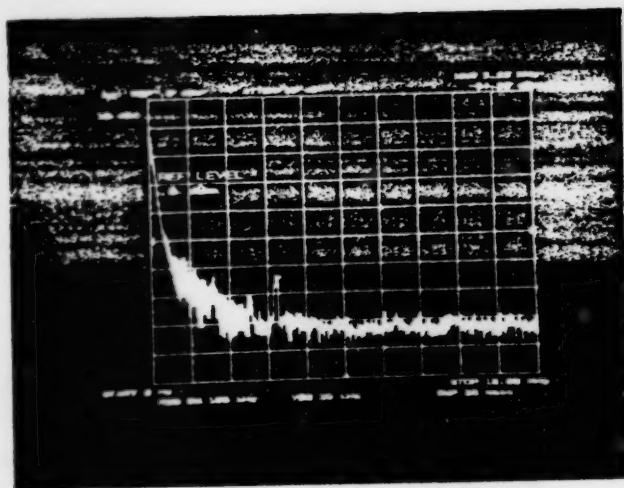
*Preamplification is 16dB.
The fine structure is not
stationary and disappears
when the key is lifted.*

FIGURE B10
SPECTRUM ANALYZER DISPLAYS 0-100kHz



a) HALF-SCREEN DISPLAY WITH KEY DEPRESSED. 0-1MHz

*Preamplification is 16dB.
The high-frequency peaks
are not stationary. Their
amplitude is in the $\mu\text{V}/\text{cm}$ range.*



b) HALF-SCREEN DISPLAY 0-10MHz

*Preamplification is 16dB.
Small peaks, such as the
one shown here at 3.2 MHz
are display dependent.*

FIGURE B11
SPECTRUM ANALYZER DISPLAYS
0-1MHz AND 0-10MHz



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ANALYSIS OF OPERATOR EXPOSURE TO
ELECTRIC FIELDS FROM
VIDEO DISPLAY UNITS

Report No 83-503-K

S.M. Harvey
Engineer/Physicist
Science Section
Electrical Research Department

ABSTRACT

When attempting to determine whether or not the electric field produced by video display units presents a hazard to human health, one needs to know the actual electric-field exposure experienced by the unit operator. In this report, electric field exposures are estimated in terms of equivalent uniform environmental fields external to the body. The environmental fields may be compared directly with fields reported for live animal or human experiments, with occupational health and safety standards, and with other natural or man-made fields in the environment. No simple comparison with fields at internal tissues or organs is possible.

job	file	date	report no.
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To Mr. R. Wilson
Director, Health and Safety

ANALYSIS OF OPERATOR EXPOSURE TO
ELECTRIC FIELDS FROM VIDEO DISPLAY UNITS

S.M. Harvey

1.0 INTRODUCTION

If sufficiently large sample and control populations are available, one can determine if any hazard is associated with an occupational exposure to electromagnetic fields and waves by performing an epidemiological study. If not, one must carry out a two-stage process in which the appropriate exposure parameters are determined through on-site measurements and the biological effects of the exposure are then determined by comparison with laboratory experiments.

The second method involves certain difficulties. For various reasons, it is often impractical or impossible to measure exposure parameters on-site and in the laboratory in a manner that allows direct comparison. Therefore before the exposures can be compared it is necessary to apply correction factors to one or the other set of measurements.

The correction factors can be very large: as much as one billion to one. Obviously, if they are neglected or applied incorrectly then the hazards will not be properly evaluated. Much of the controversy over hazards from video display units (VDUs) arises from the incorrect application or complete neglect of the necessary correction factors.

This report describes some of the factors that must be considered when evaluating the occupational exposures to electric fields produced by VDUs, and suggests some simple equivalent circuit models that may be used to assist in this evaluation. The VDU fields are then compared to some other fields to which the general population may be exposed. A portion of this work was written up earlier as a category B report/1/.

2.0 GENERAL CONSIDERATIONS

There are literally thousands of papers in the scientific literature dealing with the effects of electric and magnetic fields on humans or animals. Before the fields and exposures produced by VDUs can be compared with those described in the literature, it is necessary to be aware of certain conventions.

First, one must distinguish between environmental and perturbed fields. It is well known that a human or animal body, being highly conductive, can substantially modify, or perturb, the electric fields in its vicinity. The original unperturbed field that exists in the absence of the body is called the environmental field. The field close to the body and perturbed by it is generally higher. It is sometimes described as the vector sum of the environmental field and a field that is "scattered" by the body.

Because the measurement of perturbed electric fields is generally difficult, it is customary to describe electric field exposures in terms of the environmental field. Most environmental fields described in the literature are uniform. That is, they are essentially constant in magnitude and polarization over the volume occupied by a body. Fields from power lines, radio stations, and laboratory apparatus for exposing test animals generally meet this criterion.

The environmental field is actually a poor measure of exposure. Biological effects are produced not by the environmental fields directly but by the field strength and variation, the electromagnetic energy, or the electrical currents produced within the body by the actual fields at the surface of the test animal. All of these factors depend on the design of the test apparatus and the size, shape, and electrical properties of the animal's body, as well as the frequency or time variation of the field.

Fortunately, a great deal of work has been done on this kind of problem as a result of concerns over the biological effects of power-line electric fields/2-9/. It has been shown, when the wavelengths are long compared to the physical dimensions of the source, the distance to the person or animal, and the size of the body, that reasonable estimates of the internal fields and currents produced by a known uniform environmental field may be obtained through the application of quasistatic field theory. Reasonable estimates can also be made for short-wavelength plane wave radiation. Therefore, uniform environmental field measurements are commonly accepted as a basic measure of exposure.

Second, in some laboratory experiments animal tissue samples or organs are exposed directly to electric fields. These are also cited as environmental fields but since the environment is more appropriate to the inside of the body, the fields need to be corrected before being compared to external environmental fields. This correction is usually not made in the source literature.

Third, exposure is generally considered to be a function of both the severity of the field and the length of time during which the subject is immersed in it. Therefore an exposure measurement requires both a field value and a time factor.

Fourth, electric field strengths are usually expressed in terms of root-mean-square (rms) volts per meter (V/m). The average energy in the field is proportional to the square of the rms field strength. For sinusoidal (CW) fields, the time variation and amplitude are fully defined by the rms value and the frequency. For non-sinusoidal (eg pulsed) fields, it is also necessary to define the wave shape which may be done, for example, in terms of peak-to-peak value, zero-to-peak value, peak energy, or maximum rate of change. Spectral amplitudes are sometimes used but do not uniquely define the above parameters.

Finally, the special problems posed by small hand-operated devices must be addressed. The environmental fields produced by such devices are very nonuniform, varying by several orders of magnitude over the space normally occupied by the operator. Whereas the problems of measuring and interpreting exposure under those conditions appear to have been worked out for short wave length radiation such as that produced by microwave ovens, no established procedures for either measurement or interpretation exist for the low-frequency non-sinusoidal fields produced by VDUs.

The problems are potentially serious. For example, there is no equipment presently on the market that is capable of accurately measuring the environmental electric field close to a VDU. Published values for the local environmental electric fields are therefore suspect owing to the instrument deficiencies, and in many cases are almost certainly too high. Also, in terms of biological interactions within the body, no single measurement of the nonuniform field magnitude will adequately represent the exposure.

It is evident that a survey of VDU workplace electric fields should ideally provide a knowledge of the magnitude, spatial distribution, and time variation of the electric field over the surface of the operator's body, so that similar conditions can

be established for laboratory experiments. Failing this, one must find a method for establishing equivalence between the VDU workplace exposures as represented by available measurements and the uniform environmental field exposures which are cited in the literature and which form the basis for all occupational health and safety exposure standards. No exact equivalence can be computed from available data. However it is possible to find conservative upper limits for the equivalent environmental fields.

3.0 THE VIDEO DISPLAY UNIT

A VDU is designed to provide a visual display of information that can be read by a person seated 30 to 100 cm from the display surface. It is usually part of a computer or computer terminal which also contains a keyboard for communication in the other direction.

In order to function a VDU requires electrical energy, usually obtained from the 60 Hz power line. This energy does not disappear but is converted mainly into heat, visible radiation for display illumination, and electrical signals which may be sent along cables. Some of the energy also appears outside of the unit in the form of electric and magnetic fields.

A recent Ontario Hydro Study/10/ has shown that the electric fields are generated mainly by the circuits used to produce the nominal 15 kV dc accelerating voltage within the cathode ray tube. The magnetic fields, conversely, are produced mainly by the currents which flow through the vertical and horizontal deflection coils. The electric fields have fundamental frequencies of 0 Hz (dc), 60 Hz, and 16 to 18 kHz whereas the magnetic fields have fundamental frequencies of 60 Hz and 16 to 18 kHz. These fields fall off very quickly (roughly a $1/r^3$ dependence) with increasing distance from the unit. For all practical purposes, there are no significant field harmonics or frequencies above 300 kHz, and VDU's do not produce microwave radiation or X-rays.

When VDU operators experienced health problems ranging from headaches to birth abnormalities, it was suspected that the problems might be caused by non-ionizing radiation. In fact the fields produced by a VDU do not meet any of the criteria for a radiated wave and are therefore not radiation. However the suspicion had a valid basis in that biological effects apparently can be produced even by non-radiative fields.

Given this basis, opinion now ranges from those who believe that the VDU fields are far too benign to have any biological effect,

to those who argue that the fields are actually quite severe and clearly hazardous to the operator. Obviously this dispute can only be resolved by subjecting any comparison between estimated VDU operator exposures and those exposures known to be hazardous to careful scientific scrutiny.

4.0 ESTIMATION OF OCCUPATIONAL EXPOSURE TO VDU ELECTRIC FIELDS

The strength of the electric field produced by a VDU varies from point to point around the unit. Normally the operator occupies a position 30 to 100 cm in front of the display and this may be taken to be the area in which most exposures occur. However it has been shown that higher ac fields may exist near the back and sides of the unit. If there is a likelihood of an operator spending substantial time in these areas, eg, when operating a nearby unit, then a knowledge of the field maximum will also be necessary. In this report we will consider two "worst-case" locations, one 30 cm in front of the screen and the second 30 cm from the case of the unit in the direction of maximum ac field. For the Ontario Hydro work stations that have been surveyed, the layout generally makes it quite difficult for a person to be exposed to the maximum field with the result that data from the second location can be considered to be irrelevant for most work stations.

As mentioned previously, the electric field produced by a VDU has three components. One of these is a static or dc field, one is a low frequency field with a fundamental frequency of 60 Hz, and one is a radio-frequency field with a fundamental frequency between 16 and 18 kHz (for most units). These fields have been measured or calculated by various investigators with varying results. We will analyze each in turn and will obtain estimates of the environmental fields that should be used in evaluating work-place exposures.

4.1 DC Fields

The dc field experienced by VDU operators has been estimated to be as high as 20,000 V/m. The only known dc field measurements are described in the Ontario Hydro study report, and are perturbed body-surface field values.

The above figure results from a simple model in which the difference between a voltage on the body of the operator and the voltage on a cathode ray tube display screen (the source of the dc field) is divided by the distance between them/11/. This model would give the correct perturbed field at the surface of the operator's body if both the VDU and the operator were infinite flat plates and if the correct voltages were used.

Actually the errors in the model are rather large as can be demonstrated experimentally. Figure 1 shows that the measured surface field falls off with distance much more rapidly (between the second and third power) than the simple inverse dependence of the model. The highest surface field measured in the Ontario Hydro study was 7000 V/m at 30 cm distance from the screen, using a simulated operator at ground potential.

The model can be improved by taking into account the capacitive coupling between the operator and the VDU screen, the finite size and shape of both objects, and the presence, next to the VDU screen, of a grounded chassis. However the resulting calculations are for the most part very difficult and direct measurement is preferred.

Changes due to capacitive coupling may be demonstrated with a simple equivalent circuit model, shown in Figure 2. In this model the operator is represented by a conductor capacitively coupled to both the VDU screen at potential V_s , and remote grounded structures such as the building. It is assumed that the operator's body is at a potential V_1 relative to ground before the VDU is turned on. What, then, is the actual potential of the operator's body after the unit is energized? To answer this it is only necessary to assume that the body is electrically isolated from ground (if it is not, it will be at ground potential) so that the charge on the body is constant. Then one can calculate the new body potential to be V_2 , where

$$V_2 = V_1 \left(\frac{C_1}{C_1 + C_2} \right) + V_s \left(\frac{C_2}{C_1 + C_2} \right) .$$

This formula shows that the voltage difference between the operator and the screen is reduced by the capacitive coupling and that the change in the operator's potential relative to ground increases with increasing screen voltage. When the effects of capacitive coupling and charge transfer by atmospheric ions (if present) are taken into account it is reasonable to assume that the maximum surface field experienced by ungrounded operators will not exceed that experienced by grounded ones.

One must now take into account the difference between body surface fields and environmental fields. When a body is placed in an electric field, the field is effectively reflected from the body, or scattered. The scattered field adds to the original unperturbed field to produce local maxima at the body surface. Calculations and measurement have shown that an erect human standing in a vertical uniform environmental electric field will

experience a local body surface field as much as 25 times the unperturbed field/4/. If we use a more conservative factor of 10 then we find that a uniform environmental dc field of 700 V/m will produce the same local body surface field as does the VDU at 30 cm.

It may be concluded therefore, with due regard for the approximations in the above comparisons, that a uniform environmental field of less than 1000 V/m will provide (for comparable times) an exposure at least equivalent to that experienced at the normal VDU operator's position. As the dc field is maximum at this position, other locations around the VDU need not be considered.

The method of comparison used in the above analysis should be made quite clear. We are attempting to compare the localized dc field produced between the VDU screen and the operator with the uniform dc field in which humans or animals are immersed during biological testing, in terms of their effect on the subject. It is assumed that the biological exposures are equivalent if the two fields produce the same maximum localized field on the body surface even though the VDU field, unlike the uniform field, exposes only a portion of the body. The author is not aware of any readily testable and preferred method of comparison although there may be some reasons for introducing additional scaling factors when comparing small animals to humans. It should be noted that other methods are available for ac fields. One such method is discussed later in the report.

4.2 60 Hz Field

The 60 Hz field is produced by the same mechanism that produces the dc field and behaves in much the same manner. It results from the fact that the charge on the screen which produces the dc field is actually not constant but builds up and decays by a small amount each time the display is scanned by the electron beam. This occurs at a nominal 60 Hz rate although harmonics may exist up to several kHz. The only known measurements of the 60 Hz electric fields are also described in the Ontario Hydro study report.

No hazard is usually associated with the 60 Hz field since it may be considered to be a subset of the similar fields produced by all 60 Hz power operated equipment. By arguments similar to those used in 4.1, one may deduce that the equivalent environmental field will be less than 10 V/m rms.

4.3 16 - 18 kHz Field

This radio-frequency field is produced by the flyback transformer circuitry in which the rapid change in current through the horizontal deflection coil during the trace flyback phase is used to generate a momentary high voltage.

The high voltage is used to accelerate the electron beam. It also produces an electric field between the high-voltage circuit and external objects such as a human body which are at a lower potential. Because the distribution of this field is altered by conductive surfaces in the VDU, it can have different magnitudes in different directions relative to the front of the unit.

The time variation of the radio-frequency field is shown in Figure 3. The field is seen to be pulsating at a frequency of about 17 kHz (there is some variation between different units but a nominal value of 17 kHz is assumed). It is not a pulse-modulated radio-frequency wave.

Because the field is non-sinusoidal, it is necessary to specify several parameters relating to the wave shape. The following parameters are specified with respect to a sinusoidal field having the same rms amplitude and therefore the same average energy. Comparisons are also made to an amplitude modulated sinusoidal field.

- (a) The peak-to-peak field variation is about 1.8 times that of the sinusoidal field. It is the same variation that would result if the sinusoidal field were 80% amplitude modulated, as may occur with AM radio broadcast signals.
- (b) The peak instantaneous field strength is three times greater, and the peak instantaneous energy is therefore nine times greater. For the modulated sinusoidal field the corresponding factors are 1.7 times and 2.8 times.
- (c) The maximum rate of change of the field, whose importance will be noted later, is six times greater than that of a sinusoidal field having a frequency of 17 kHz and equal to or less than that of a sinusoidal field having a frequency of 100 kHz or greater.

Having specified these parameters, one can now proceed to evaluate operator exposures in terms of rms field strength. A considerable amount of data resulting from reputable measurements on a total of 100 different units (some unreported) is now available for this evaluation/10,12,13/.

we will consider first the measurements of the localized environmental field at a distance of 30 cm from the unit. These measurements show that for most units the electric field strength in front of the unit is less than 1 V/m rms. No field strengths greater than 5 V/m rms have been measured at this position. At the position of maximum field strength, the highest reading that has been obtained is 200 V/m rms (excluding one device that has been withdrawn from the market). As noted previously, some of these readings may be too high: a recently discovered problem with the measuring instrument causes it to record VDU field values as much as two or three times greater than the actual rms field.

Until this problem is resolved, values of 5 V/m and 100 V/m may be considered as conservative upper limits for the uniform environmental radio-frequency fields corresponding to the two exposure positions.

An alternative set of measurements is provided by the Ontario Hydro survey which has included nine units. In this survey the maximum body surface radio-frequency field recorded with a simulated operator at 30 cm from the display screen was 35 V/m rms. For seven of the nine units the surface field was less than 10 V/m rms. If the factor of 10 previously used for the dc field is applied to these measurements, the data are entirely consistent with the previously noted environmental field measurements at the operator's position.

In this survey, complete measurements of the maximum fields at 30 cm from the back or side of the units were not made. However the data suggest that the previously quoted value of 200 V/m may indeed be two or three times too high. Therefore the results of the Hydro survey further support the conservative upper limits noted above.

When comparing ac field exposures there are in fact several processes that may be used to establish equivalence. We have already used the process in which the exposures are deemed equivalent if they produce the same local maximum field at the surface of the body. An alternative process is often used in evaluating exposures to power system fields/8/. In the latter, exposures are deemed to be equivalent if they produce the same current flow through the body. In the following analysis we estimate equivalent environmental fields in terms of current flow.

4.4 Radio-Frequency Environmental Field Estimates from Current Flow

In order to explore the possibility of using current flow for estimating environmental fields, detailed measurements were made on one VDU. This unit had the second highest radio-frequency field of the units included in the Hydro survey.

For the measurements, the simulated body was connected to ground and the radio-frequency current flowing through the ground wire was measured. This is the current that must flow into and out of the body in order to maintain the body at a constant potential in the presence of the radio-frequency electric field.

An equivalent circuit for the grounded configuration may be obtained by shorting out capacitor C_1 in Figure 2. The resulting circuit is shown in Figure 4 where C_3 replaces C_2 because the source of the voltage is now the flyback transformer and not the display screen. Since for the radio-frequency situation capacitor C_1 may be assumed to be much greater than C_3 , it is evident that grounding the body will not have a great effect on the total current although the current distribution through the body may be altered.

From Figure 4 it is seen that the instantaneous current will be

$$i = C_3 \frac{dv_{fb}}{dt}$$

That is, the current is proportional to the rate of change of the flyback voltage and hence is also proportional to the rate of change of the electric field. This dependence is confirmed experimentally. Note that the capacitance between the operator and the flyback circuit can be calculated from the above equation. Assuming that the peak flyback voltage is 15 kV, one finds that C_3 is about 0.02 pf.

The measured maximum rms surface fields and the measured rms currents are listed in Table I, as are the currents measured for a real body. The real body currents are in satisfactory agreement with those obtained from the simulator, the differences probably being due to the use of an average male body whereas the simulator represents an average female body and is therefore smaller.

One must now calculate the uniform environmental field that will produce the same current. Fortunately a suitable equivalent circuit model is available/9,14/ and is shown in Figure 5. The model assumes that the human is standing erect on a conductive ground plane in the presence of a uniform vertically-polarized environmental electric field E (V/m). The parameters which have been determined for this model are available in the literature and are: $C = 100$ pf, $L = 0.48$ m. When the calculations are performed for a field having the same time variation as the VDU field, the equivalent environmental fields shown in the 4th row of Table I are obtained.

Table I shows that the environmental fields obtained in this way are up to 3 times smaller than those obtained by equating maximum surface fields. The current method tends to average the effects of the field over the body and is therefore less dependent on the variation of the field at a highly localized position on the body.

TABLE I

RADIO-FREQUENCY SURFACE FIELDS AND BODY-TO-GROUND CURRENTS
MEASURED WITH SIMULATED OPERATOR,
WITH EQUIVALENT ENVIRONMENTAL FIELDS

	Position	
	Front, 30 cm	Maximum, 30 cm
1. Measured surface field V/m rms	12	220
2. Equivalent environmental field (surface method) V/m rms	1.2	22
3. Measured current μ A rms	29	200
4. Equivalent environmental field (Current method) V/m rms	1.1	7.7
5. Measured current, real body (Compare to #3) μ A rms	34	210

4.5 Radio-Frequency Field Summary

To conclude this discussion of radio-frequency field exposures, the data may be summarized as follows:

- At the operator's position, the uniform environmental field giving an equivalent "worst-case" exposure for equal time is typically less than 1 V/m rms and does not exceed 5 V/m rms.
- At the position of maximum field 30 cm away from the unit, the uniform environmental field giving an equivalent exposure is typically less than 8 to 22 V/m rms, depending on the method of comparison, and does not exceed an estimated value of 100 V/m rms.

5.0 REMARKS ON INTERNAL BODY FIELDS

In this section, we look at the problem that presents by far the greatest difficulties. This occurs when published field values refer to intracellular or extracellular fields or to fields to which internal body tissues or organs are exposed. The reason for the difficulty is that it is necessary to know the electrical properties of the body in considerable detail before internal fields can be calculated from external fields or vice versa.

It seems clear that if one has a reasonably accurate electrical model of the human or animal body in terms of the bulk properties of the various tissues, then this information can be combined with a knowledge of the size and shape of the body and the distribution of the field over the external surface of the body to give reasonably accurate estimates of the fields and currents that will exist at the larger internal organs. By this means one could, for example, compare effects between humans and small animals by accounting for differences in body shape and size. Such comparison are made for power-frequency fields.

However, for cellular effects or tissue close to the body surface, it is likely that the heterogeneity of the tissues will have to be taken into account.

The author has no special knowledge of the body's electrical properties and has ready access to only a small portion of the available literature, which remains primarily in the domain of the Health Scientist or the Biologist. It is of interest, however, to see what workers in these fields have stated in a fairly random selection of papers from the published literature about the present state of the art. For example:

"For low-frequency electric fields, the electric field shielding effectiveness of the chest cavity is excellent, with well over 100 dB suppression of the exterior fields."

This statement is from a paper investigating, with large animals, the effect of electromagnetic fields on heart pacemakers/17/. A graph of chest model calculations shows shielding that varies inversely with frequency. The calculated suppression at 20 kHz is 90 dB, or a factor of 30,000.

"The ratio of the electric fields in tissue is approximately the same in the case of a $10 \mu\text{A}/\text{cm}^2$ current density at the surface of an Aplysia nerve cell and the case of a man exposed to a 2 kV/m unperturbed field."

"Coupling of environmental fields to whole organisms and isolated tissues depends on the field frequency. For ELF fields of 10-1000 V/cm, tissue gradients are in the range of 10^{-7} to 10^{-5} V/cm. To achieve a tissue gradient of 10-100 mV/cm with ELF fields alone would require an environmental field of 500 000 V/m."

These statements are from a DOE study of tissue interactions/15/. The second quote suggests two different factors for the ratio between internal and external fields, 10^{-8} and 10^{-5} . Probably the first applies to surface fields and the second to "unperturbed" fields.

"The field to which experimental subjects are exposed is almost always specified in terms of its unperturbed value, ie its configuration and strength with the subject absent.----- a quantitative understanding of this interaction is necessary to relate the electric fields actually experienced by the subject - the surface fields and the fields induced within the body - to the unperturbed field."

"In the ELF range, conductivities of human and animal tissues are reasonably independent of frequency ----. Electrical permittivities of tissues are very large ($>10^5 \epsilon_0$) in the ELF range ---. Analysis beyond that given in this paper is required to relate, for example, the actual fields experienced by an individual cell to the bulk electric fields or current density in the tissue containing the cell."

"The induced field inside the body is very small. Equation 6 evaluated for tissue in the ELF range gives

$$|\vec{n} \cdot \vec{E}_i| > 10^{-7} |\vec{n} \cdot \vec{E}| \text{ at the surface of the body.}$$

These quotes are from a Pacific Northwest Laboratory paper on body interactions/2/. The last one states that the normal E-field component inside the body is 10^{-7} of the normal E-field component outside the body.

"A common misinterpretation is to extend effects on subjects, such as fish in conducting media, to erect humans in a non-conducting atmosphere on a simplistic volts-per-meter comparison basis -----. Fortunately, studies that adequately considered the physical and biological factors have been conducted in the last few years."

This quote is from a recent IEEE review article/6/.

It seems reasonable to conclude from these articles that a considerable amount of work has been done in recent years on the relation between external and internal electric fields and that over the frequency range of interest for VDU's the ratio of the fields is generally thought to be of the order of 30 000:1 on the basis of this work, indicating that published fields for internal tissue should be increased accordingly before being compared with external fields.

It is worth noting that if the energy in the field is the important biological parameter, then the difference between the outside and the inside of the body will be 10^9 :1 based on an electric field ratio of 30 000:1.

6.0 COMPARISON BETWEEN VDU ELECTRIC FIELDS, AMBIENT FIELDS, AND OCCUPATIONAL EXPOSURE GUIDELINES

In the preceeding sections we have obtained estimates for the uniform environmental fields which provide "worst-case" exposures equivalent to those experienced by VDU operators if present for the same periods of time. These fields may be compared to existing occupational exposure standards and also to the fields that are present in the environment as a result of the common use of power and communications systems.

Figure 6 shows such a comparison for the fields at the VDU operator's position. The frequency domain representations (or spectral amplitudes) are drawn from a variety of sources and are, for most practical purposes, the maximum fields that may be encountered from the indicated equipment. The occupational exposure guidelines are those in effect in several industrial countries. No attempt has been made to include all sources of electric fields.

7.0 SUMMARY AND CONCLUSIONS

Although many measurements have been made of the electric fields produced by video display units, there seems to be little agreement as to the meaning of the measurements in terms of actual human exposure. In the long term, it is human exposure defined in terms of time and some appropriate field variable or variables that will determine whether or not the fields are hazardous.

In order to simplify the evaluation of exposure hazards, we have estimated from various measured VDU fields the upper limits for uniform unperturbed fields that are thought to be most equivalent in terms of human exposure. Uniform unperturbed (or environmental) field values may be compared directly with the fields cited for laboratory experiments on humans, and with some appropriate scaling factors, for experiments on small animals, as well as with the fields cited in occupational exposure guidelines. They cannot be compared directly with the fields cited for experiments on tissue samples or internal organs.

The electric field produced by a VDU contains three components. One is a static or dc field. The other two are ac fields with nominal fundamental frequencies of 60 Hz and about 17 kHz. Actual equivalent uniform environmental fields cannot be calculated from available measurements. However by making "worst-case" assumptions throughout, it is possible to obtain definitive upper limits for the equivalent field components. These upper limits cover measurements on 100 different units.

Expressed in terms of equivalent uniform environmental fields, the maximum values of the three field components at the operator's normal position (30 cm or more from the display screen) do not exceed the following:

dc field	- 1000 V/m
60 Hz field	- 10 V/m rms
17 kHz field	- 5 V/m rms

For the majority of the tested units, the maximum value for the 17 kHz field component is substantially smaller (<1 V/m rms). This component may exist with higher values (typically <22 V/m rms but not exceeding an estimated maximum of 100 V/m) at 30 cm from the back or sides of some units. Measurements which tend to average this very localized field over the surface of the body give considerably lower environmental field values.

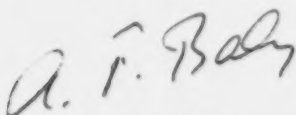
Because the 17 kHz field is pulsating rather than sinusoidal, the peak values should also be recorded. Thus the peak instantaneous field is three times that of a sinusoidal field having the same rms amplitude and the peak instantaneous energy is nine times as great. These ratios are substantially reduced if the sinusoidal field is amplitude modulated as would be the case for fields from an AM radio transmitter.

In a spectral amplitude representation, the environmental fields at the operators normal position are found to be smaller than bracketing fields produced by 60 Hz power operated equipment or AM radio stations in an urban environment, and to be much smaller than any occupational exposure guidelines.

The radio-frequency field produced by VDUs actually lies in a "hole" in the environmental electromagnetic spectrum that exists between power frequencies and communications frequencies. Not surprisingly, there has been very little research carried out on interactions between biological systems and electric fields in the vicinity of this hole, and possible health hazards can at present only be assessed by interpolation between higher and lower frequencies. A simple interpolation suggests that a VDU work station may actually be one of the safer places to work. However, in the long term, only further research can replace speculation with fact.

Approved:

Submitted:



A.F. Baljet
Manager
Electrical Research Dept

SMH:djb



S.M. Harvey
Engineer/Physicist
Science Section



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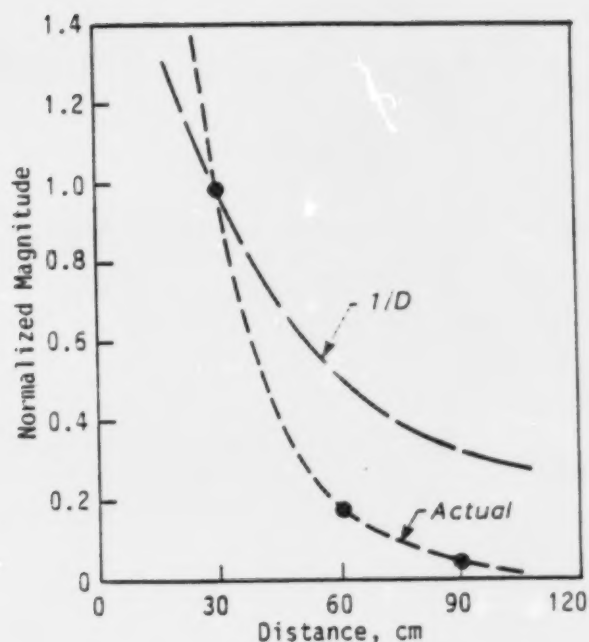


FIGURE 1
THEORETICAL INVERSE-DISTANCE VARIATION COMPARED TO
ACTUAL dc FIELD MEASUREMENTS VERSUS DISTANCE FROM
THE DISPLAY SCREEN. BOTH CURVES ARE NORMALIZED
TO VALUES AT 30 cm

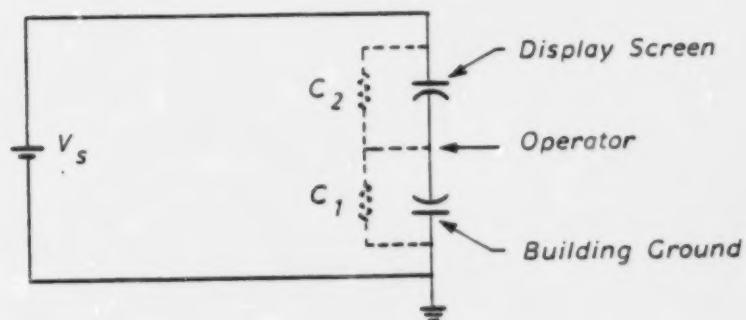


FIGURE 2
EQUIVALENT CIRCUIT OF A VDU OPERATOR CAPACITIVELY COUPLED TO
BOTH THE VDU DISPLAY SCREEN AT VOLTAGE V_s AND THE
BUILDING AT GROUND POTENTIAL. IT IS ASSUMED THAT
THE OPERATOR IS CONDUCTIVELY ISOLATED FROM GROUND.
THE RESISTORS (DASHED LINES) REPRESENT THE EFFECT OF
ATMOSPHERIC IONS, IF PRESENT

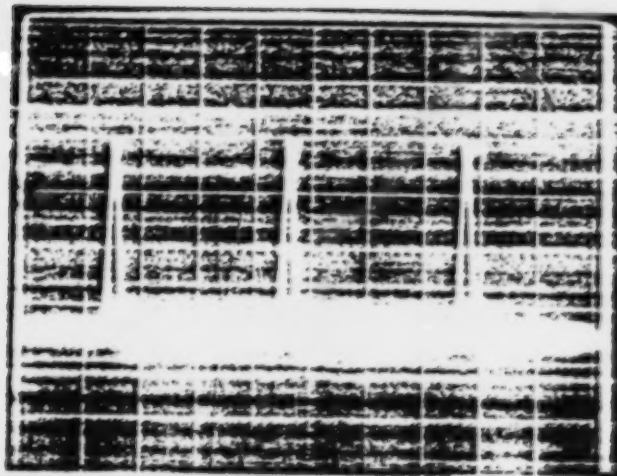


FIGURE 3
TIME VARIATION OF THE RADIO-FREQUENCY ELECTRIC FIELD
PRODUCED BY A VDU. THE HORIZONTAL SCALE IS 20 μ s/DIV

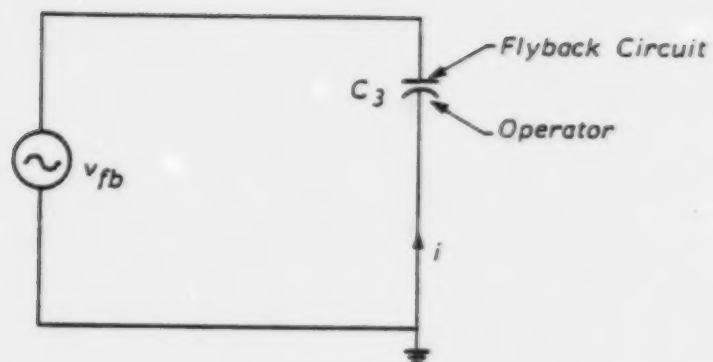


FIGURE 4
EQUIVALENT CIRCUIT OF A VDU OPERATOR CAPACITIVELY COUPLED
TO THE VDU FLYBACK CIRCUIT AT VOLTAGE v_{fb} . v_{fb} IS
A PULSATING VOLTAGE. i IS THE RESULTING CURRENT
BETWEEN THE OPERATOR AND GROUND

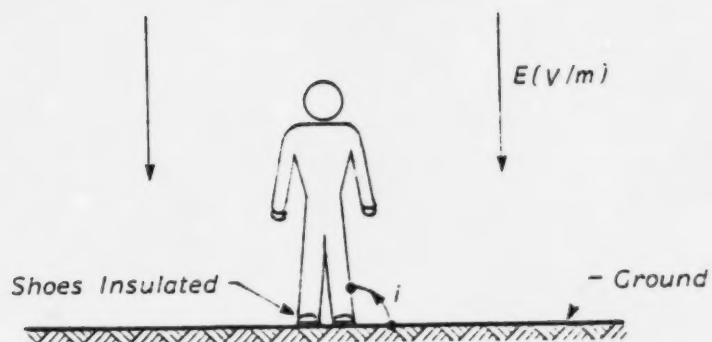


FIGURE 5 (a)

MODEL FOR THE EQUIVALENT CIRCUIT OF A PERSON EXPOSED
TO A UNIFORM ENVIRONMENTAL FIELD OF E V/m.
 i IS THE RESULTING CURRENT BETWEEN
THE PERSON AND GROUND

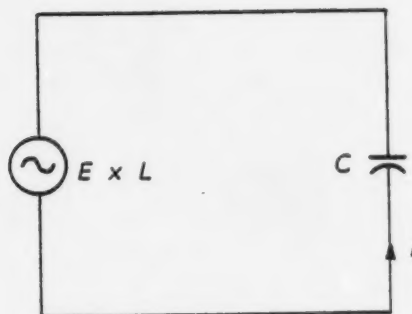


FIGURE 5 (b)

EQUIVALENT CIRCUIT FOR (a). C AND L ARE
CONSTANTS TO BE DETERMINED EITHER
BY EXPERIMENT OR CALCULATION

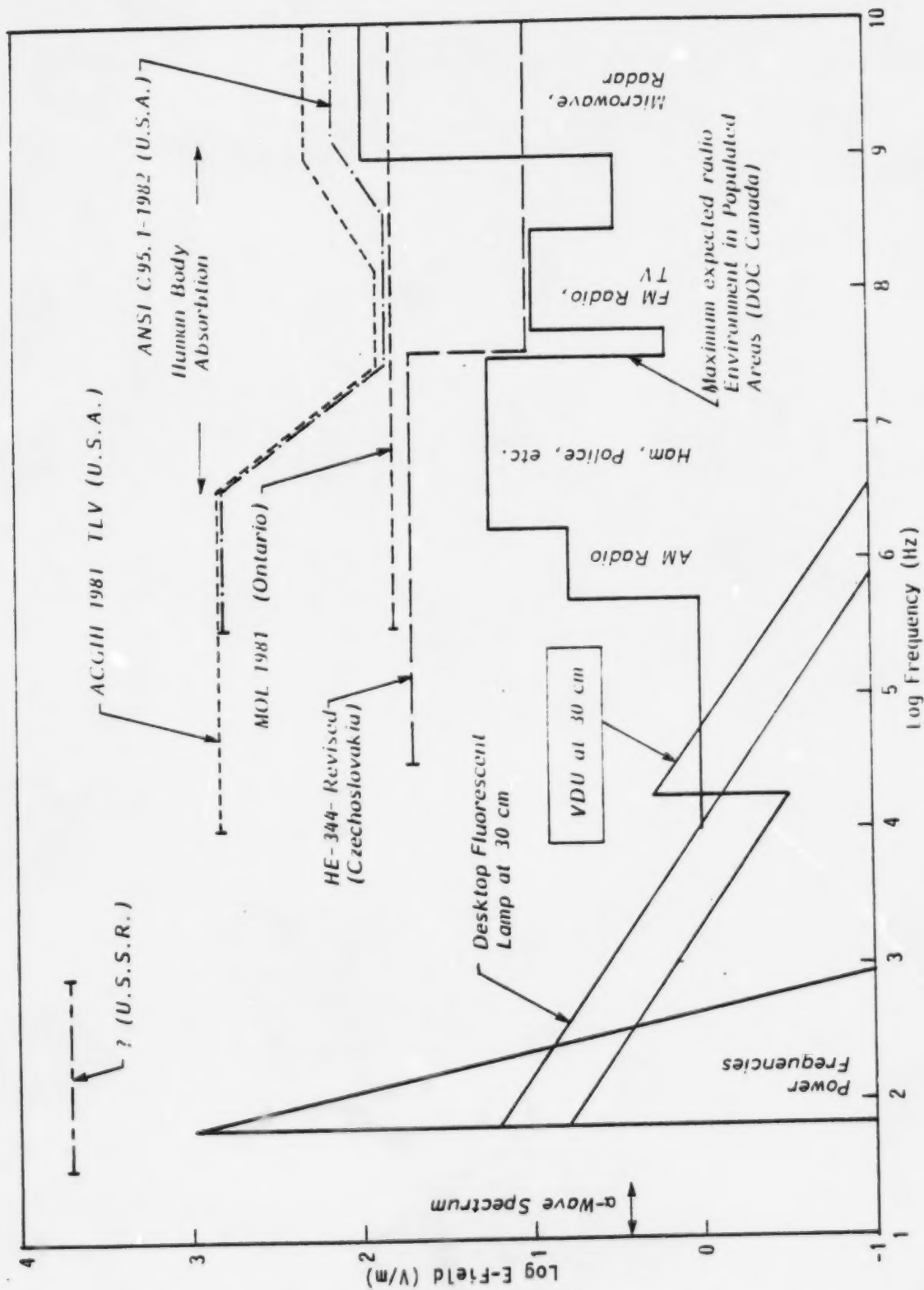


FIGURE 6

FREQUENCY DOMAIN REPRESENTATION OF VDU ELECTRIC FIELDS AT OPERATOR'S POSITION COMPARED TO
 (a) OTHER FIELDS AND (b) EXISTING 8 HOUR DAY EXPOSURE GUIDELINES (DASHED CURVES).
 Note: The Low-Frequency Spectral Amplitude Functions are Rendered as Straight Lines for Simplicity





ontario hydro
research division

To Mr. R. Wilson
Director
Health and Safety Division

CHARACTERIZATION OF LOW FREQUENCY MAGNETIC
FIELDS PRODUCED BY VIDEO DISPLAY UNITS

S.M. Harvey

As part of a study of health hazards from video display units, operator exposure to low-frequency magnetic fields has been measured over a frequency range from 10 Hz to 1 MHz. The magnetic fields are energetically somewhat stronger than the corresponding unperturbed electric fields but still cannot be related to any known health effects.

1.0 INTRODUCTION

This report is one of a series whose purpose is to fully characterize the electric and magnetic fields that are produced by video display units (VDUs). The information about electric and magnetic fields is required as part of an interdivisional program established to assess the possible health hazards to which VDU operators might be exposed.

Measurements of electric fields were described in a previous report/1/. In that work, partly in order to avoid serious instrumentation problems, an infrequently used (but valid) measurement technique was employed that took into account the changes in the field produced by the presence of a conductive body. Procedures for comparing these measurements with measurements commonly reported in the literature are described in a second report/2/.

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In the present work, measurements are made of the magnetic fields produced by VDUs. Fortunately, the magnetic fields are not appreciably altered by the presence of a human body so that the measurements can be made and interpreted in a simple manner without the need for various corrections. The information in this report should therefore fulfil the same objective for magnetic fields as the previous two reports did for electric fields; namely, to provide a detailed characterization of field exposures that will be experienced by the VDU operator.

2.0 MEASURING EQUIPMENT

It is much easier, in principle, to measure VDU magnetic fields than electric fields. The presence of any metal or other conductive material in a field probe will perturb, or change, the electric field configuration under most measurement conditions. On the other hand, magnetic materials are usually necessary to significantly change the magnetic field readings and such materials can be avoided in the sensor design. This does not, however, mean that the measurements are free of problems.

First, if the sensor is not carefully designed it will respond not only to magnetic fields but also to electric fields at the same location, thereby yielding incorrect data. Sensitivity to electric fields can be minimized through the use of adequate shielding and by operating the sensor in a "balanced" configuration.

Second, the sensor will average the field over its effective area. If the sensor is large, as may be required to give an adequate response, and the field is changing rapidly with distance, then a displacement error will occur. In other words, the measurement will correspond not to the field along the sensor axis, but to the field along an axis displaced towards the higher field. If necessary, the error may be estimated and a correction made.

The measurements described in this report were made with two air-cored copper-wound coils which covered the frequency range from 10 Hz to 1 MHz in two overlapping bands. The low-frequency coil was designed to have a flat response from 60 Hz to 6 kHz and the high-frequency coil was designed to have a flat response from 6 kHz to 600 kHz. Therefore, undistorted field waveforms may be observed within these bands.

Both coils were heavily shielded and were operated in a balanced configuration into the differential input of a Tektronix 5103N Oscilloscope with type 5A22N high-gain differential plug in.

This combination was determined experimentally to provide adequate rejection of electric-field pickup. Waveforms were recorded photographically from the CRT screen. Spectral amplitudes were obtained with HP3582A and HP8568A Spectrum Analyzers.

Construction and calibration details for the two coils may be found in Appendix A.

3.0 UNITS SELECTED FOR TESTS

The video display units selected for the magnetic-field measurements were units 1, 2 and 3 as identified in the previous report/1/. The units are of varying age and represent three different manufacturers. They include the unit found to have the highest electric-field emissions among all of the tested units to date (nine in total).

4.0 FIELD CHARACTERISTICS

All three units were found to produce qualitatively similar magnetic fields. In each case the magnetic field is the sum of two separate contributions, one having a fundamental frequency of about 60 Hz and the other having a fundamental frequency equal to that produced by the flyback transformer, between 16 and 18 kHz. These will be described, respectively, as the 60 Hz and the 17 kHz fields. The field characteristics are described below with the range of field parameters indicated in each case. A complete description of the field measurements obtained for one unit is given in Appendix B. Field values at the operator's position are summarized in Table I. The field values reported in this work are in essential agreement with those published previously by other workers/3,4/.

TABLE I

SUMMARY OF MAGNETIC FIELDS MEASURED AT A DISTANCE OF 30 cm FROM THE DISPLAY SCREEN. UNITS ARE AMPERES PER METER (A/m)

	VDU		
	1	2	3
60 Hz field - rms amplitude	0.20	0.56	0.12
17 kHz field - rms amplitude	0.035	0.110	0.025

60 Hz Field

The 60 Hz field contribution contains components from several locations within the unit, including the power supply. However, the main contribution to this field comes from the vertical deflection yoke, or coil, used to displace the electron beam from top to bottom of the display screen at a nominal 60 Hz rate.

The vertical deflection coil is mounted with its field axis horizontal and parallel to the screen surface. The polarization of the field at the operator's position is in the same direction, as expected from geometrical considerations.

The field distribution is nearly spherical around a point close to the deflection coil, indicating that, unlike the electric fields, it is not significantly distorted by metallic or conductive materials within the set. The magnitude of the field falls off approximately with the inverse third power of the distance from the center point (a $1/r^3$ dependence).

The wave form of the 60 Hz component is approximately a "sawtooth" for which the rms amplitude is 0.3 times the peak-to-peak amplitude. Rms amplitudes at a position 30 cm in front of the display screen range from 0.12 A/m to 0.56 A/m. Changes in the format or intensity of the visual display have no visible effect on this component. No frequency components below 60 Hz or any contribution from the keyboard could be observed.

17 kHz Field

The main contribution to the high-frequency magnetic field component comes from the horizontal deflection coil. There appears to be also a small contribution from the flyback transformer circuitry.

Since the field axis of the horizontal deflection coil is in the vertical direction, one would expect that the field at the operator's position would be similarly polarized. For the unit having the strongest field, this expectation is confirmed. Conversely, the weaker the field, the less likely is the polarization to have a predictable direction.

The field distribution, like the low-frequency component, is nearly spherical around a point close to the deflection coils and falls off approximately with the inverse third power of the distance from this point.

The wave form of the high-frequency component is also approximately a "sawtooth". Rms amplitudes at a position 30 cm in front of the display screen range from 0.025 A/m to 0.110 A/m. Changes in the display have no apparent effect on this component.

5.0 EFFECT OF ADDED SHIELDING

Metal shielding placed between the deflection coils and the field sensor had very little effect on the amplitude of the magnetic field. Specially fabricated mu-metal shields may be effective but were not tested.

6.0 COMPARISON WITH A COLOUR TV RECEIVER

For comparison purposes, magnetic fields produced by a 20-inch colour TV receiver of recent manufacture was measured. At a distance of 30 cm from the front of the set the low-frequency component had an amplitude of 1.0 A/m rms and the high-frequency component had an amplitude of 0.38 A/m rms. A person sitting 1 m (3 ft) from this TV receiver would be exposed to the same high-frequency field as a person sitting 30 cm (1 ft) from a typical VDU.

7.0 REMARKS CONCERNING POSSIBLE HEALTH EFFECTS

The measurements made in this study show that no VDU operator will be exposed to low-frequency magnetic fields in excess of any known occupational health and safety standards.

Electric and magnetic fields may be compared on the basis of the energy per unit volume of the field, the field strength ratio E/H for equal energy being 377 (ohms). On this basis it may be determined that the magnetic fields at the operator's position are up to 100 times more energetic than the corresponding unperturbed or environmental electric fields. The significance, if any, of this difference in terms of human health is not known.

8.0 CONCLUSIONS

Low-frequency magnetic fields produced by a selection of video display units have been measured. Unlike electric fields, these fields are essentially unchanged by the presence of a human body and therefore no body simulation was used or corrections made.

The fields are composed of two components:

1. A sawtooth-type field produced mainly by the vertical deflection coil and having a nominal fundamental frequency of 60 Hz. The rms amplitude of the field at a distance of 30 cm from the display screen is in the range from 0.12 to 0.56 A/m for the units tested.
2. A sawtooth-type field produced mainly by the horizontal deflection coil and having a fundamental frequency between 16 and 18 kHz. The rms amplitude of the field at a distance of 30 cm from the display screen is in the range from 0.025 A/m to 0.110 A/m for the units tested.

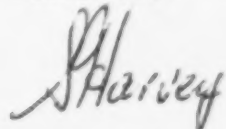
These fields are characteristic of raster-scan CRT devices, including television sets. The measurements rated in this report are in essential agreement with data published by other investigators but provide more complete information about both the time and the space variations of the fields.

In the frequency range from 10 Hz to 1 MHz, no fields having characteristics presently known or suspected of being detrimental to human health were found. Unlike electric fields, the magnetic fields cannot be easily reduced by the application of local shielding.

Approved:

Submitted:

A.F. Baljet
Manager
Electrical Research Dept


S.M. Harvey
Engineer/Physicist
Science Section

SMH:ljh

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APPENDIX A

FIELD MEASUREMENT EQUIPMENT AND CALIBRATION

1. Coil Design

The coils used for the magnetic field measurements were constructed by winding a number of turns of fine copper wire onto non-ferrous metal forms. Slots were cut in the metal forms to prevent currents from circulating around them.

Coil winding was done in a manner that ensured turn symmetry about a center-tap ground connection for balanced operation. The complete coils, including the cable conductors, were enclosed in continuous grounded metallic shields and were gymbal mounted for measurement convenience. Each coil was terminated in a carbon resistor selected to provide a voltage output independent of frequency over the desired range.

The coils are shown in Figure A1 and the construction details are provided in Table A1. Calibration and frequency response data, obtained with large-diameter source loops, are shown in Figure A2.

Coil voltage output is unaffected by the load impedance of the measuring device so long as this impedance is large compared to the terminating resistor. Therefore different measuring devices may be used without affecting the calibration. In the present work the coil outputs were measured with the following instruments.

- (i) Tektronix 5103N oscilloscope with 5A22N high-gain differential-input plug in amplifier. Bandwidth adjustable up to dc to 1 MHz. Input impedance 1 M Ω shunted by 47 pf.
- (ii) HP3582A Spectrum Analyzer. Frequency range 0 to 25 kHz. Input impedance 1 M Ω shunted by 60 pf.
- (iii) HP8568A Spectrum Analyzer. Frequency range 100 Hz to 1.5 GHz. Input impedance 50 Ω .
- (iv) HP3400A true rms voltmeter. Frequency range 10 Hz to 10 MHz. Input impedance 10 M Ω shunted by 40 pf.

Displacement errors with coils 1 and 2 were estimated to be up to 5% for locations 30 cm or more from the unit. These errors

cause the coil to read high. However no corrections were made as the slight improvement in measurement accuracy would not materially affect the results.

TABLE A1

COIL CHARACTERISTICS

Coil Number	Number of Turns	Mean Diameter	Terminating Resistor
1	2000	19 cm	47 Ω
2	90	11 cm	15 Ω

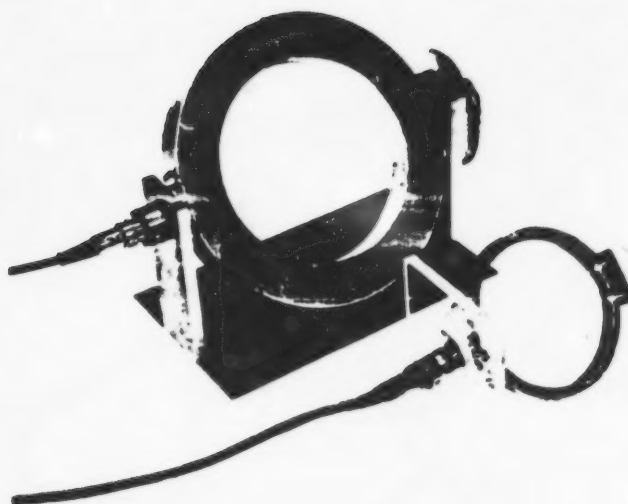


FIGURE A1
PHOTOGRAPH OF MAGNETIC FIELD
SENSING COILS

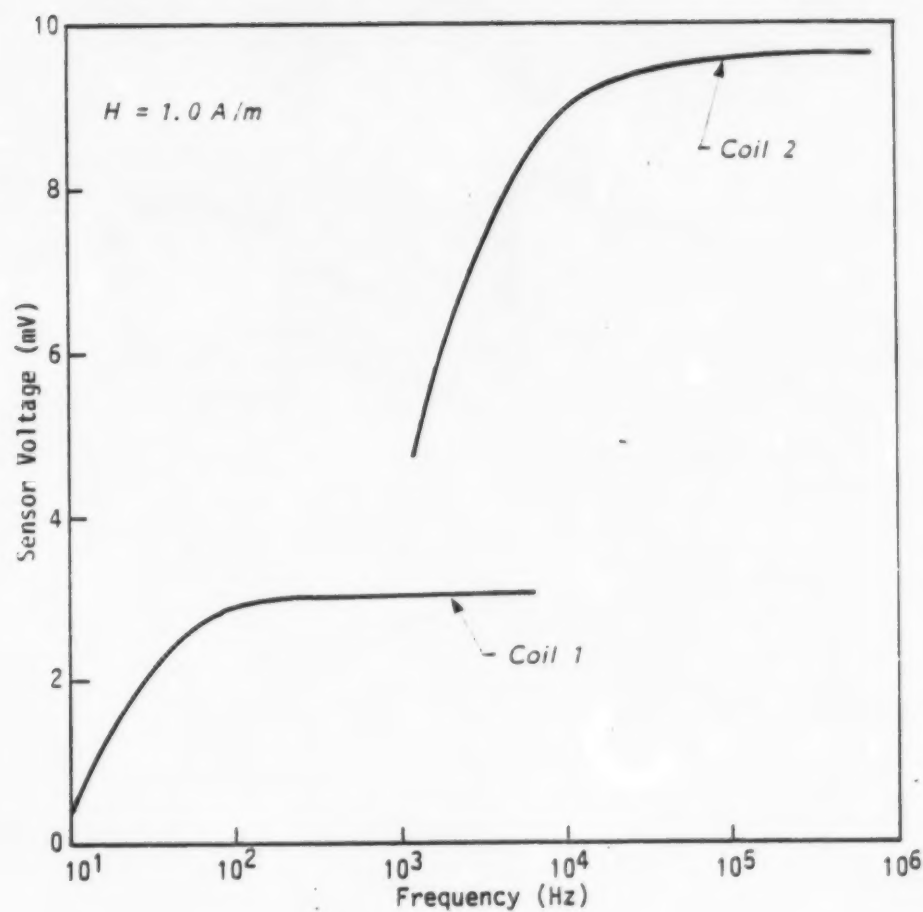


FIGURE A2
CALIBRATION CURVES FOR
MAGNETIC FIELD SENSING COILS

APPENDIX B

DETAILED STUDY OF LOW-FREQUENCY MAGNETIC FIELDS PRODUCED BY A VIDEO DISPLAY TERMINAL

In this appendix, a detailed description is given of the magnetic-field measurements obtained with one of the tested units. The unit selected is the same one (Unit 1) that was described in detail in the previous report on electric fields.

1. METHOD OF MEASUREMENT

For field measurements, the VDU was placed on a wooden table near the center of a basement room with a low background level of extraneous fields.

Identical measurement procedures were followed with both the low-frequency and the high-frequency coil. They were as follows:

- (a) The coil was moved around the unit in a horizontal plane passing through the center of the CRT. At each measurement location the coil was rotated around the gymbal axes until the maximum peak-to-peak voltage was displayed on the oscilloscope. This voltage was recorded.
- (b) The coil was moved around in a vertical plane passing through the CRT axis. Peak-to-peak voltage measurements were recorded as in (a) for the region in front of the display screen.
- (c) The coil was positioned at a point 30 cm in front of the display screen and the maximum peak-to-peak voltage was recorded. The coil was then oriented along each of three mutually perpendicular axes and photographs were obtained of the resulting field waveforms.
- (d) Finally, a spectrum analyzer display of the harmonic content of the low- or high-frequency field was recorded. During this display, the brightness and other screen parameters were varied to see if any effect could be observed. None was.

2. RESULTS

2.1 AC Fields Below 6 kHz

Measurements of low-frequency magnetic fields could be obtained with reasonable accuracy only within about 50 cm of the unit, owing to a general background of 60 Hz magnetic field in the room.

Plots of the spatial distribution of low-frequency field are shown in Figures B1 and B2. The field is seen to have approximately a spherical distribution around a point located close to the CRT deflection coils. This point is actually located between the deflection coils and the unit power supply. The field waveforms showed mainly a nominal 60 Hz sawtooth-type waveform, with some power frequency harmonics superimposed. It is assumed that the latter contributions originated with the power supply, whereas the sawtooth originated with the vertical deflection coil which carries a ramp-type current having a nominal repetition frequency of 60 Hz (if interlace is not used).

The X, Y, and Z components of the low-frequency magnetic field in front of the display screen are shown in Figure B3. These waveforms support the supposition that the magnetic field has more than one source and therefore more than one direction of polarization at the measurement point, although clearly the deflection coil field predominates.

Spectrum analyzer displays of the low-frequency field waveform are shown in Figure B4. It is noted that measureable 60 Hz harmonics extend beyond 5 kHz but that there are no components below 60 Hz.

Rms voltmeter measurements confirmed that the ratio of rms to peak-to-peak voltages was close to 0.3 for the observed waveforms.

2.2 AC Fields Above 6 kHz

Measurements made with the high-frequency coil showed that there was also a magnetic field component having a fundamental frequency of 15.9 kHz. This is the frequency at which the CRT beam is deflected horizontally across the display screen in the unit under test and is also the flyback transformer frequency, the deflection current being the source of the high voltages on the secondary of the transformer.

Plots of the spatial distribution of the high-frequency magnetic field are shown in Figures B5 and B6. The field is seen to have approximately a spherical distribution around a point located close to the deflection coils or, in this case, between the deflection coils and the flyback transformer circuit. The field waveforms show mainly a 15.9 kHz sawtooth waveform which is assumed to originate with the horizontal deflection coil. Also present is a lower amplitude component which resembles the electric field produced by the flyback circuit and which may therefore be attributed to this circuit.

The X, Y, and Z components of the high-frequency magnetic field in front of the display screen are shown in Figure B7. As was the case for the low-frequency field, these waveforms support the supposition that the high-frequency field has more than one source although the deflection coil field again predominates.

A Spectrum analyzer display of the high-frequency field is shown in Figure B8, where it can be seen that the measurable harmonics extend only up to 300 kHz. In contrast, the high-frequency electric field harmonics extended to about 1 MHz. This difference should not be surprising as the voltage pulse that produces the electric field is derived by differentiating the current that produces the magnetic field.

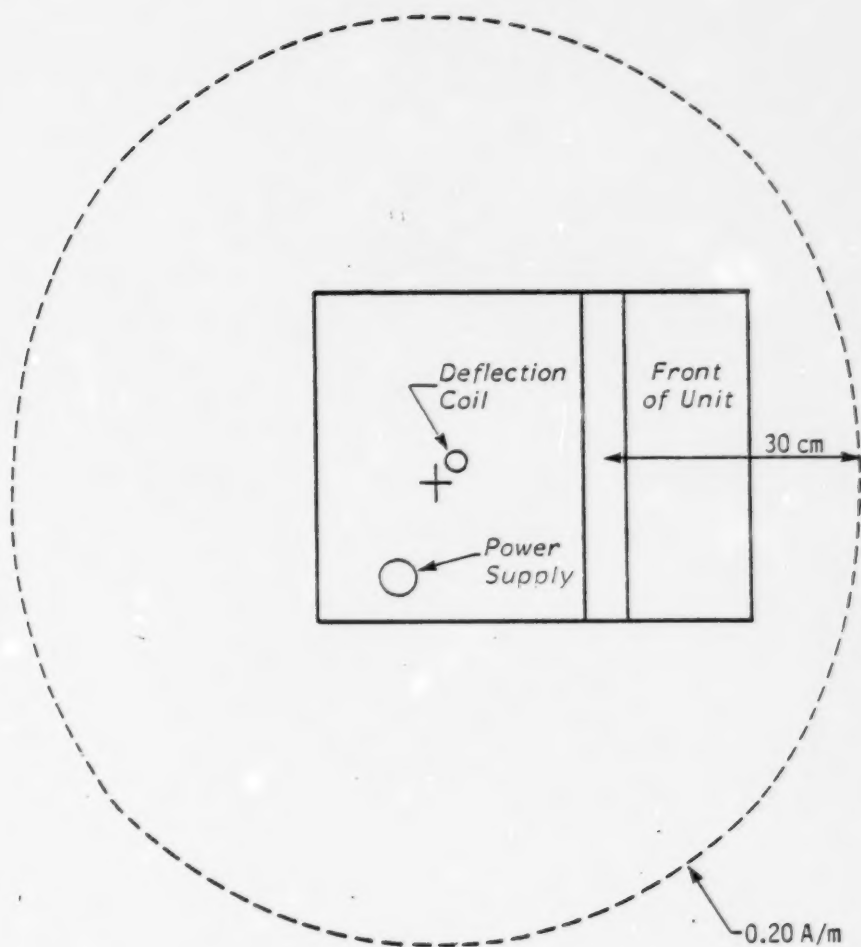


FIGURE B1
 SPATIAL VARIATION OF LOW-FREQUENCY
 MAGNETIC FIELD IN HORIZONTAL PLANE.
 UNITS ARE A/m rms (PEAK-TO-PEAK x 0.3)

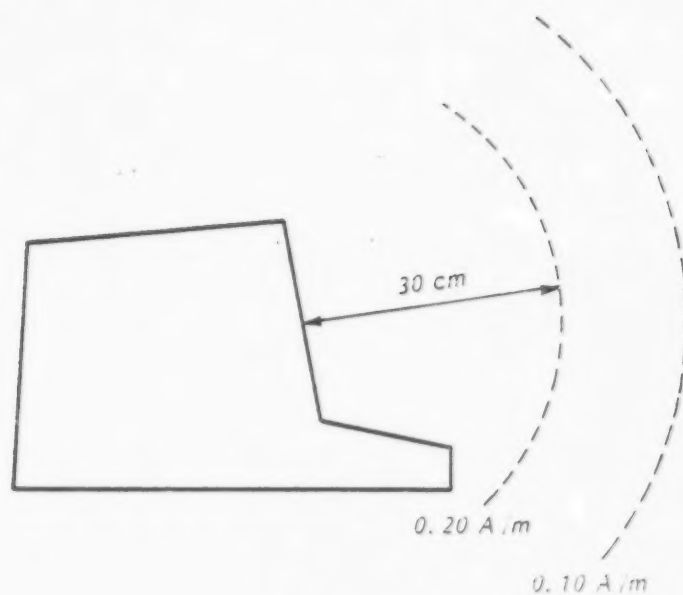
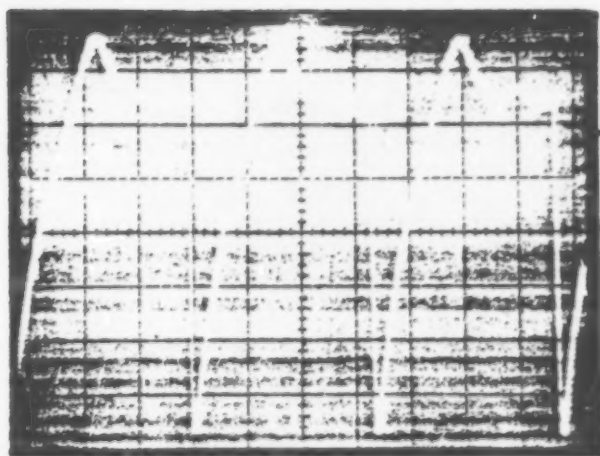
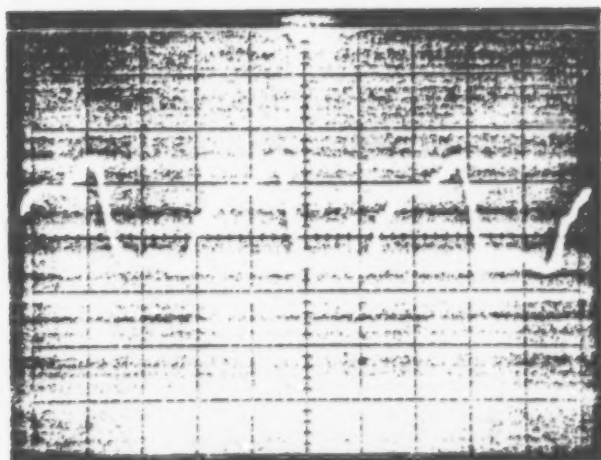


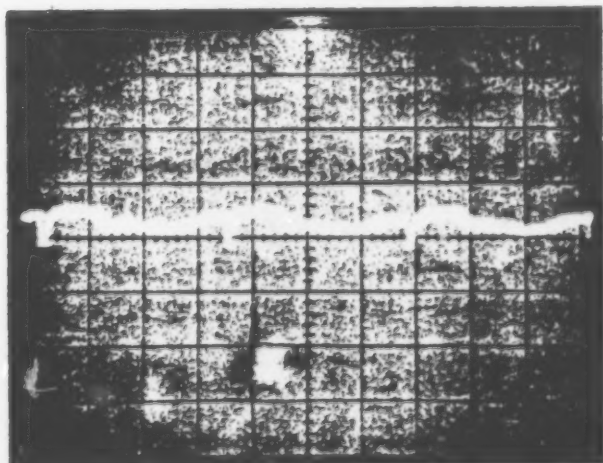
FIGURE B2
SPATIAL VARIATION OF LOW-FREQUENCY MAGNETIC FIELD
IN VERTICAL PLANE. UNITS ARE A/m rms
(PEAK-TO-PEAK X 0.3)



X-Axis



Y-Axis



Z-Axis

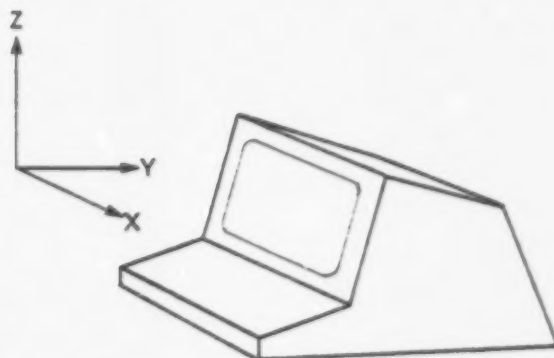


FIGURE B3

LOW-FREQUENCY MAGNETIC FIELD
WAVEFORMS MEASURED WITH
SENSOR AXIS ORIENTED IN
Z, Y AND Z DIRECTION
30 cm FROM DISPLAY SCREEN

VERTICAL SCALE IS 0.2 mv/DIV
HORIZONTAL SCALE IS 5 ms/DIV

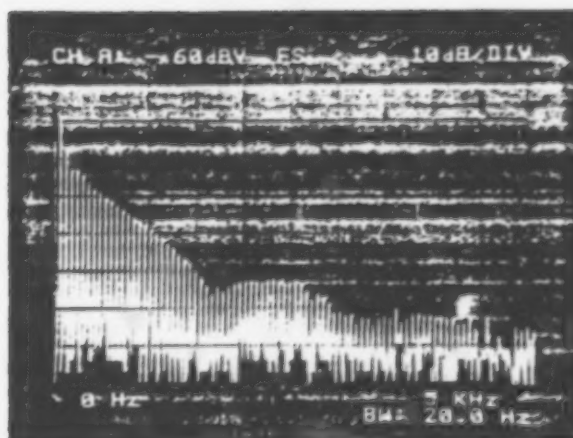


FIGURE B4(a)

SPECTRUM ANALYSER DISPLAY OF LOW-FREQUENCY
MAGNETIC FIELD WAVEFORM. SENSOR IS ORIENTED
FOR MAXIMUM SIGNAL. THE FREQUENCY RANGE IS
0 TO 5 kHz. THE VERTICAL SCALE IS
LOGARITHMIC (10 dB/DIV)

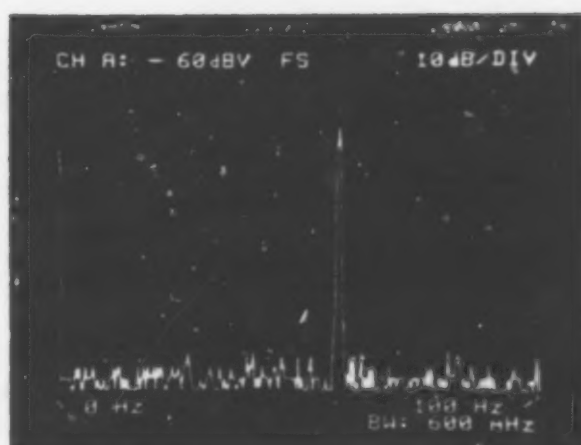


FIGURE B4(b)

EXPANDED PORTION OF FIGURE B4(a).
THE FREQUENCY RANGE IS 0 TO 100 Hz

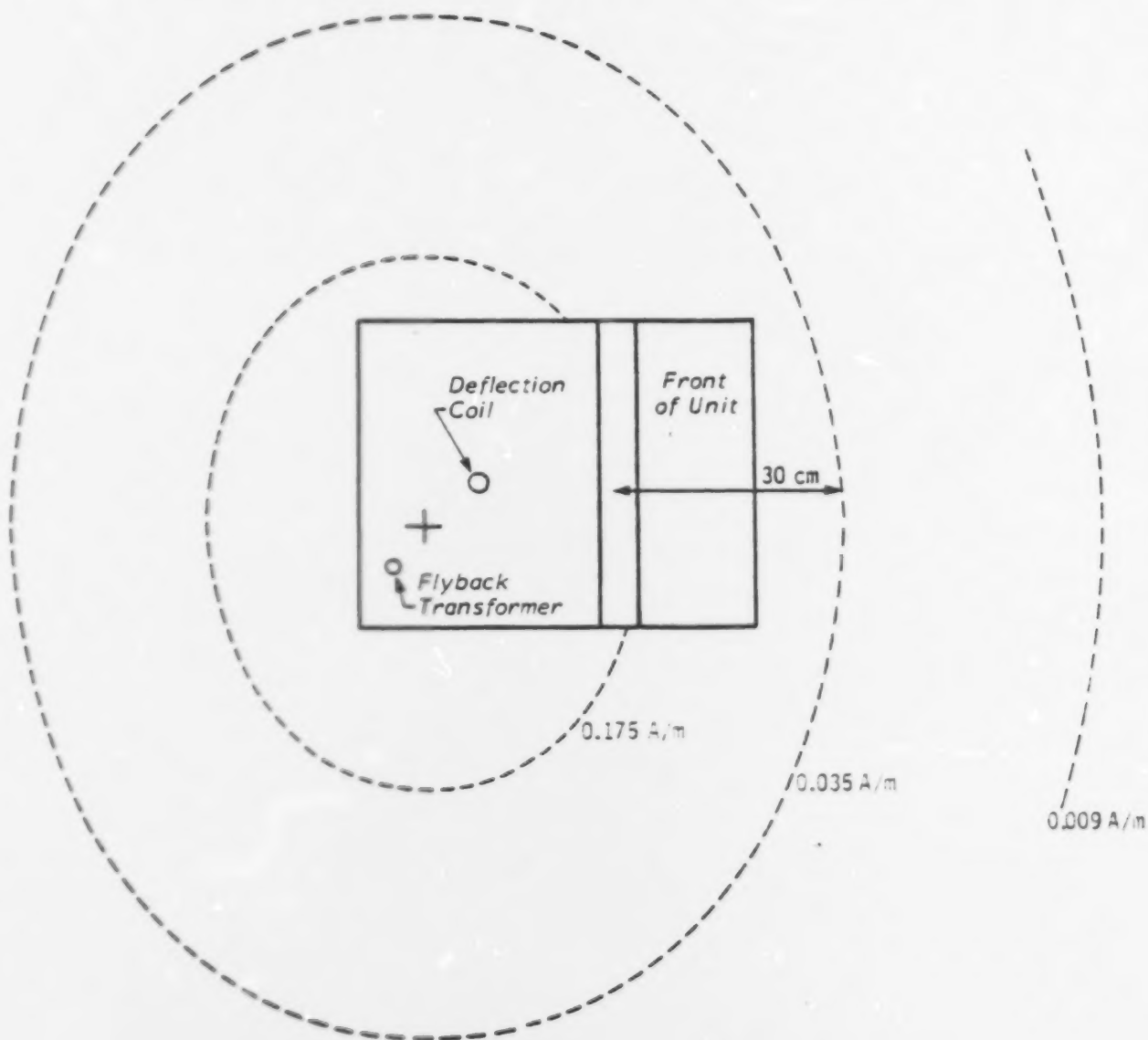


FIGURE B5
 SPATIAL VARIATION OF HIGH-FREQUENCY
 MAGNETIC FIELD IN HORIZONTAL PLANE.
 UNITS ARE A/m rms (PEAK-TO-PEAK $\times 0.3$)

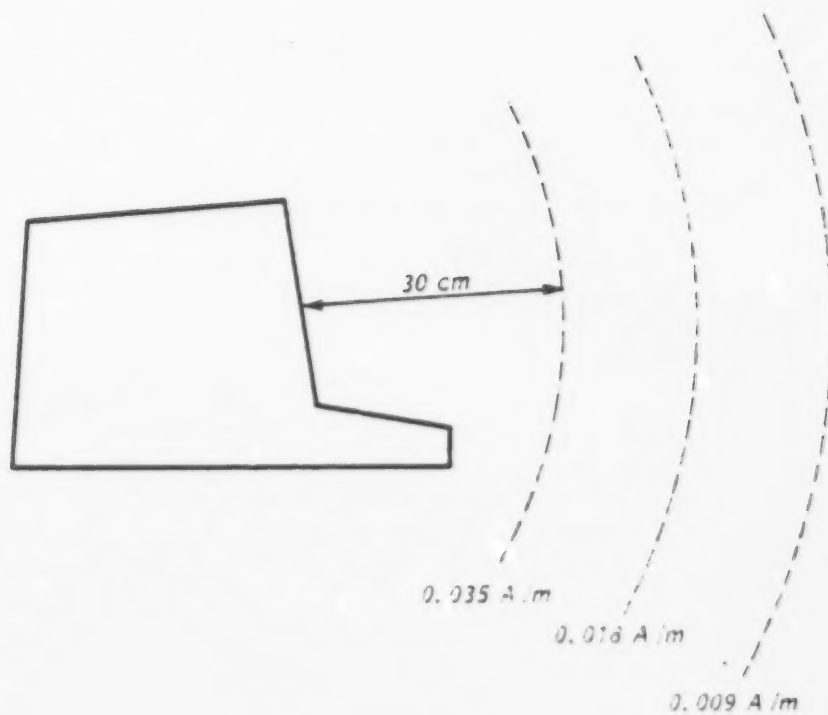
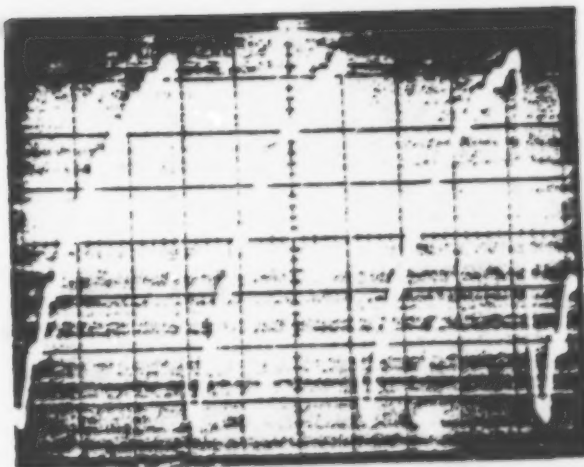
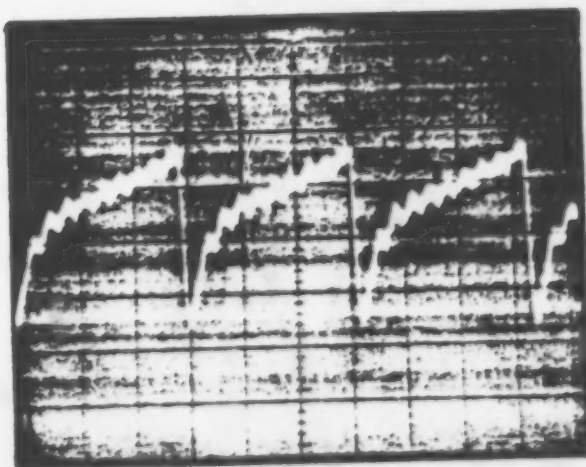


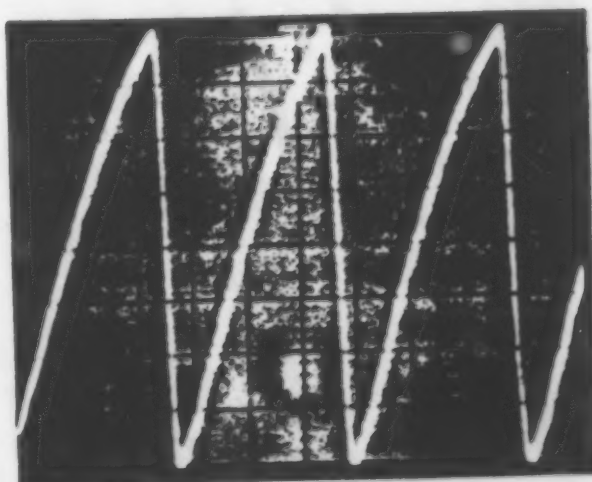
FIGURE B6
SPATIAL VARIATION OF HIGH-FREQUENCY
MAGNETIC FIELD IN VERTICAL PLANE.
UNITS ARE A/m rms (PEAK-TO-PEAK X 0.3)



X-Axis



Y-Axis



Z-Axis

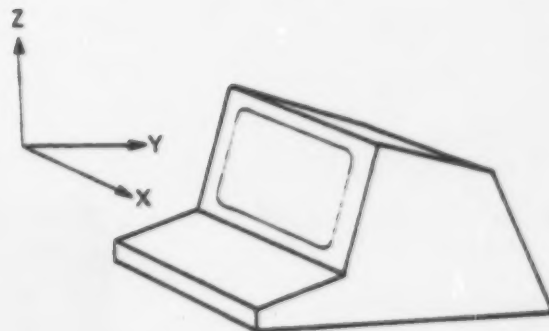


FIGURE B7
HIGH-FREQUENCY MAGNETIC FIELD
WAVEFORMS MEASURED WITH
SENSOR AXIS ORIENTED IN
X, Y AND Z DIRECTIONS
30 cm FROM DISPLAY SCREEN
VERTICAL SCALE IS 0.1 mv/DIV
HORIZONTAL SCALE IS 20 μ s/DIV

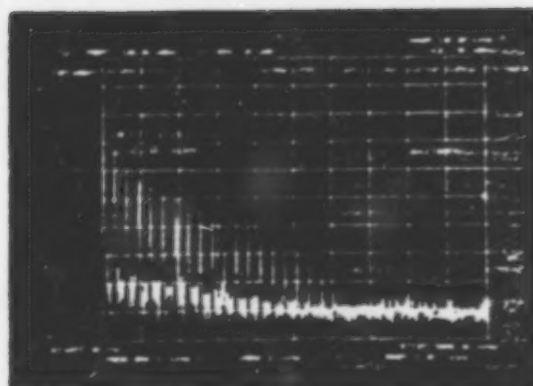


FIGURE B8
SPECTRUM ANALYSER DISPLAY OF HIGH-FREQUENCY
MAGNETIC FIELD WAVEFORM. SENSOR IS ORIENTED FOR
MAXIMUM SIGNAL. THE FREQUENCY RANGE IS 0 TO 300 kHz.
THE VERTICAL SCALE IS LOGARITHMIC (10 dB/DIV)



ontario hydro
research division

To Mr. R. Wilson
Director, Health and Safety

SURVEY OF ELECTRIC AND MAGNETIC FIELDS
AT ONTARIO HYDRO VDU WORK STATIONS

S.M. Harvey and L. Starecky

Electric and magnetic fields produced by video display units at 54 different Ontario Hydro VDU workstations have been measured. Together with previous data obtained in the laboratory, the survey results provide a broad database for evaluating operator exposure to low-frequency VDU fields.

1. INTRODUCTION

In 1982, the Health and Safety Division of Ontario Hydro launched a broadly based program to evaluate any health and safety risks that might be associated with the operation of video display units (VDUs). As part of this program the Research Division carried out a detailed investigation under laboratory conditions of the electric and magnetic fields produced by a small number of VDUs in the frequency range from dc to beyond 1 MHz. The Laboratory study has been written up in three Research Division reports/1,2,3/.

The present report describes measurements that were made of the principal field components at 54 different Ontario Hydro VDU workstations. This survey greatly extends the number of different models for which data are available and also provides data representing actual office conditions.

The Ontario Hydro survey differs in several important respects from other surveys that have been reported in the literature/4,5/. First, it provides information about the electrostatic or dc component of electric field. Second, it provides measurements that may be more directly associated with biological effects at the surface of or within the body. Finally, a complete record of all radio-frequency electric and magnetic field waveforms was obtained. For the purposes of this report, the results are presented in terms of equivalent environmental fields so that they may be compared to other published data.

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2. SELECTION OF UNITS FOR THE SURVEY

There are nearly 2000 VDUs in Ontario Hydro Offices. As it was neither practical nor necessary to test all units, many of them being identical models, a selection was made based on the following criteria:

- If possible, at least one unit of each model represented should be tested.
- The survey should include about 50 units in order to provide a meaningful statistical base.
- The selected units should form a subset of the units previously tested by Health and Safety Division for X-ray emissions.

The final selection, itemized later in the report, includes 54 units representing 18 different manufacturers. When these units are added to the ones previously studied, the total number of tested units is 63, representing 20 manufacturers.

3. TEST AND MEASUREMENT PROCEDURE

A complete description of the characteristic electric and magnetic fields produced by VDUs may be found in References 1 and 3. It is shown in these reports that the only fields strong enough to be of possible biological significance are (a) an electrostatic field, (b) electric and magnetic fields having a fundamental frequency of 60 Hz, and (c) electric and magnetic fields having a fundamental frequency in the region of 16 to 18 kHz.

The 60 Hz fields are similar to those produced by common ac-powered appliances and have not been proposed as a possible health hazard. Therefore only the (a) and (c) components were measured. For convenience, these will be referred to as the dc component, and the radio-frequency or 17 kHz components. All measurements were made with the sensors and procedures described in references 1, 2 and 3, to which the technically inclined reader may refer for further information.

The electric field measurement techniques used in the present work do not directly yield values for the free-space or "environmental" electric fields produced by the VDU. They yield instead the value of the surface electric field on a simulated operator's body at the point of closest approach to the VDU (Method A) or the value of the body current produced by the field averaged over the body (Method B). Such measurements are of considerable biological interest but must be converted to

environmental fields before a comparison can be made with the fields reported in other literature. The conversion factors are not generally known and therefore, to avoid confusion, all measurements in this report are converted to equivalent environmental dc or rms (root-mean-square) fields by methods which are fully described in Reference 2.

As with all available techniques, there is some imprecision in the reported field values. However, as the conversion factors are considered to be conservative, it may be assumed that occupational exposures experienced by VDU operators will generally be lower than those indicated by the survey data.

All units were tested in an "as found" condition during normal office hours. The dc field and the radio-frequency electric and magnetic fields were measured at a position 30 cm (1 foot) from the display screen. This point is considered to be the normal operator's position although the actual operator's distance may vary from 30 cm to 100 cm. Electric field values at this position were measured by Method A only as Method B usually gives nondetectable results.

A contentious issue raised by some investigators involves apparent high radio-frequency electric fields near the back or sides of some units. It has been suggested that such local maxima could expose office staff to potentially hazardous fields. In order to test this hypothesis, the position of the local maximum was located for each unit and measurements were made at this position 30 cm from the VDU enclosure by both Method A and Method B. If no such local maximum was found, then these measurements were made at the front of the VDU.

Although electric-field measurements at distances closer than 30 cm are occasionally reported, such measurements are known to be questionable owing to sensor design factors and were not attempted in this work. Normally this space is not occupied by office personnel, except perhaps momentarily, and therefore will make no significant contribution to occupational exposures. If information is required about electric-field distributions at distances of less than 20 to 30 cm, it would be necessary to use either mathematical computation or a test technique that had been validated for these highly non-uniform fields.

The step-by-step procedure followed by survey personnel is described in Appendix A.

4. VDU WORKSTATION FIELDS

The survey results are presented in convenient bargraph form in Figures 1 to 4. Figures 1 and 2 show respectively the dc field

value and the 17 kHz electric field value at the operator's normal position. Figure 3 shows the 17 kHz electric field values obtained at the position of the local maximum, and Figure 4 shows the 17 kHz magnetic field values at the operator's normal position. The statistical variations are summarized in Tables I and II.

Some of the units included in the survey produced atypical electric and magnetic field waveforms. For these units the rms field values, which are all computed using the conversion factors obtained in references 2 and 3, will be moderately in error. However, the effect on the statistical distribution is not thought to be significant.

A complete listing of the survey data, together with product identification, is provided in Appendix B.

5. ANALYSIS AND DISCUSSION

As noted previously, the measurements obtained in this survey are expressed in terms of equivalent environmental fields. One of the advantages of this procedure is that the fields may be compared with other fields in the environment, in most cases without further correction. Occupational exposures, usually considered to be the product of the environmental field and the time spent at the measurement position, may also be directly compared.

The conversion from actual measurement to environmental field is not very precise, owing to the lack of adequate theoretical models. However, as conservative measurement techniques and conversion factors are used, it is likely that the occupational exposures obtained from the reported data will be on the side of safety.

The results show that at 30 cm from the VDU the maximum environmental DC field is 1500 V/m. The unit producing this field is a conventional 26 inch colour TV set that is used for display purposes.

The maximum 17 kHz environmental electric and magnetic fields at 30 cm from the display screen are 2.7 V/m rms and 0.16 A/m rms respectively. The maximum 17 kHz environmental electric field in any direction is between 5 and 15 V/m rms depending on the method of measurement. As noted in the references, the higher value results from a measurement over the 100 cm² area of the body that is closest to the VDU and the lower value represents the average value of the field over the whole body.

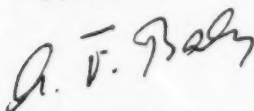
Median values of all fields are substantially lower.

The results of this survey further support the conclusions in the Ontario Hydro laboratory study and other surveys that the electric and magnetic fields at any normal working distance from a VDU are actually quite low and are comparable to other environmental fields/6/. Occupational exposure to these fields will be well below any presently known risk thresholds.

6. CONCLUSIONS

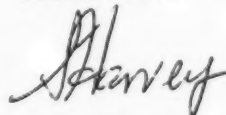
Biologically equivalent environmental electric and magnetic fields have been estimated from measurements of the local fields produced by VDUs at 54 different Ontario Hydro workstations. These fields may be compared to other electric or magnetic fields in the environment or used to evaluate occupational exposures. The occupational exposures for all of the surveyed units are found to be too low to be associated with any known health risk.

Approved:

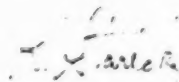


A.F. Baljet
Manager
Electrical Research Dept

Submitted:



S.M. Harvey
Engineer/Physicist
Science Section



L. Starecky
Engineer
Science Section

SMH/LS:km

TABLE I

Statistical variation of environmental electric and magnetic fields measured at 30 cm from the VDU display screen. Environmental fields are derived by Method A (see text).

Field Description	Field Strength		
	Minimum	Median	Maximum
dc, V/m	-300	+35	+1500*
17 kHz electric, V/m (rms)	0.05	0.48	2.64
17 kHz magnetic, A/m (rms)	0.005	0.050	0.160

* this unit is a conventional 26-inch colour TV set used for display purposes.

TABLE II

Statistical variation of environmental 17 kHz electric fields measured at the local maximum position 30 cm from the VDU enclosure. Environmental fields are derived by two methods (see text). ND means not detectable.

Method	Field Strength		
	Minimum	Median	Maximum
A, V/m (rms)	0.05	0.53	14.4
B, V/m (rms)	ND	ND	4.64

ELECTROSTATIC (DC) FIELD

Normal Position

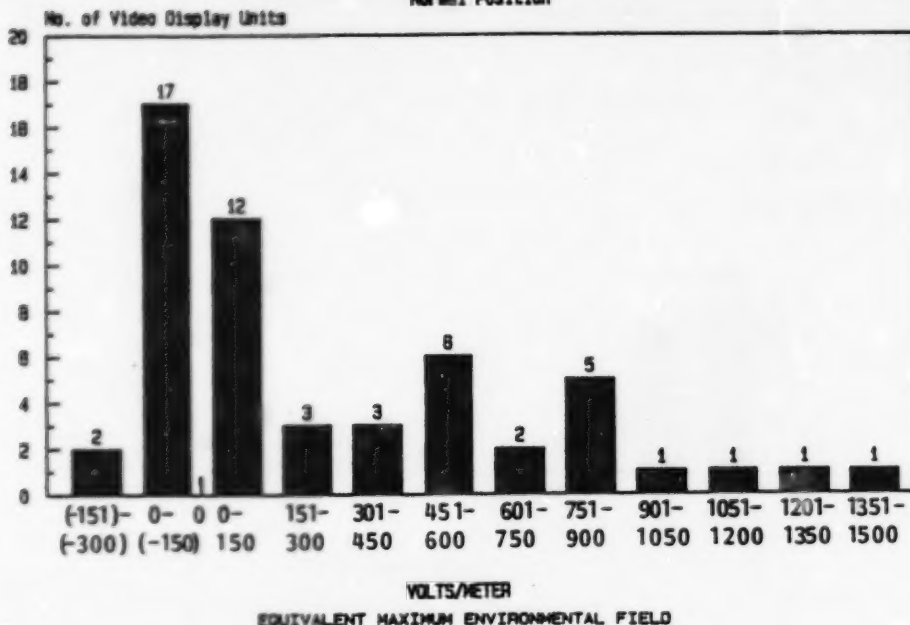


FIGURE 1

ENVIRONMENTAL DC ELECTRIC FIELDS -
NORMAL POSITION

RADIO FREQUENCY ELECTRIC FIELD

Normal Position

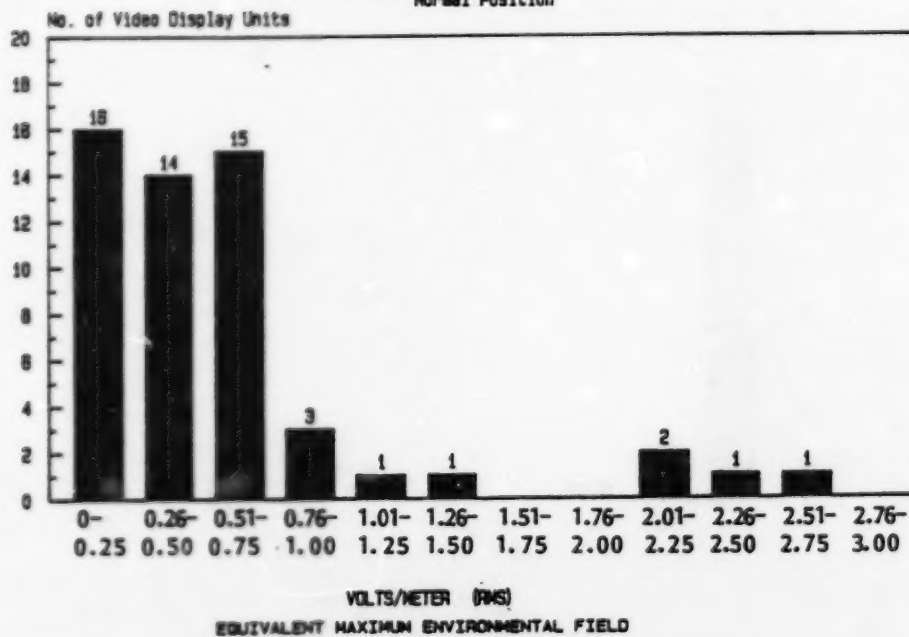
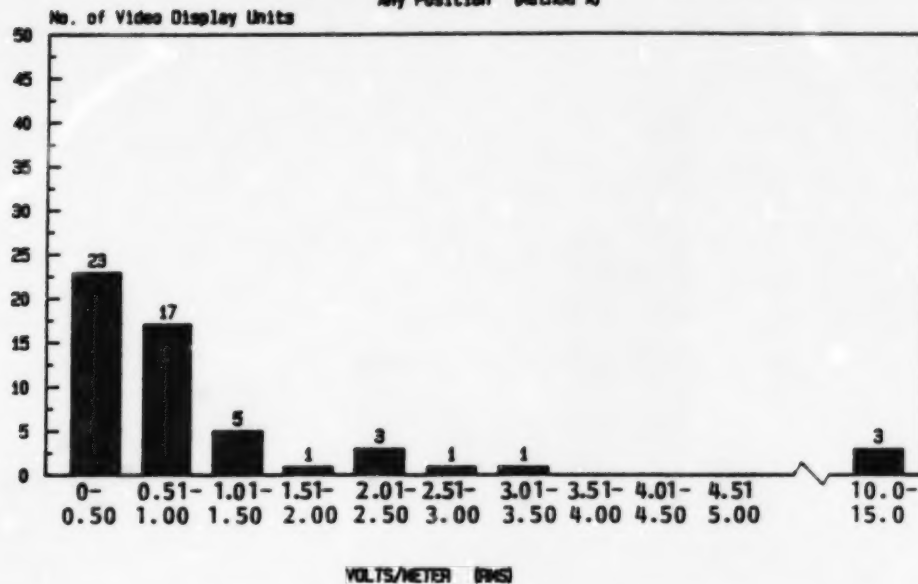


FIGURE 2

ENVIRONMENTAL 17kHz ELECTRIC FIELDS -
NORMAL POSITION

RADIO FREQUENCY ELECTRIC FIELD

Any Position (Method A)



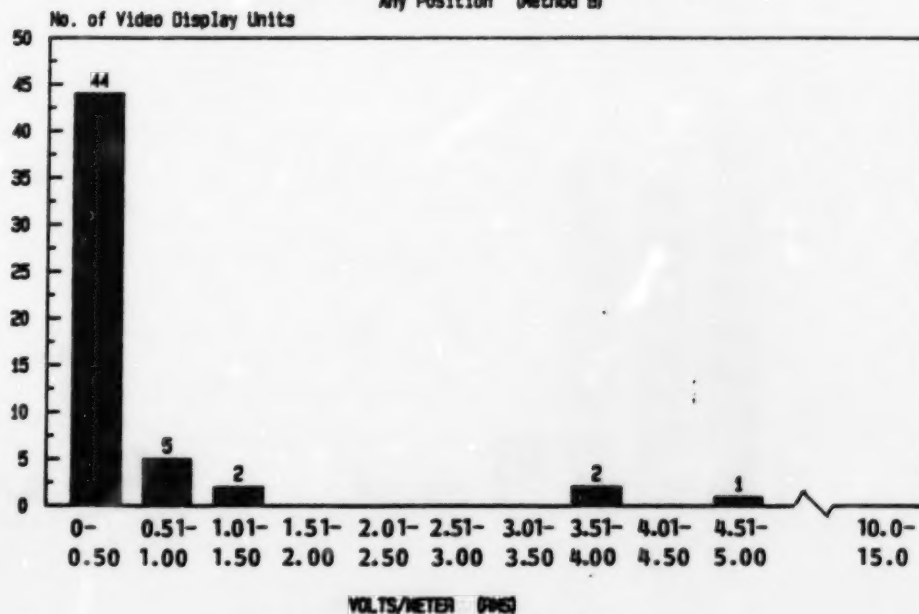
EQUIVALENT MAXIMUM ENVIRONMENTAL FIELD

FIGURE 3(a)

ENVIRONMENTAL 17kHz ELECTRIC FIELDS AT
POSITION OF LOCAL MAXIMUM, METHOD A

RADIO FREQUENCY ELECTRIC FIELD

Any Position (Method B)



EQUIVALENT MAXIMUM ENVIRONMENTAL FIELD

FIGURE 3(b)

ENVIRONMENTAL 17kHz ELECTRIC FIELDS AT
POSITION OF LOCAL MAXIMUM, METHOD B

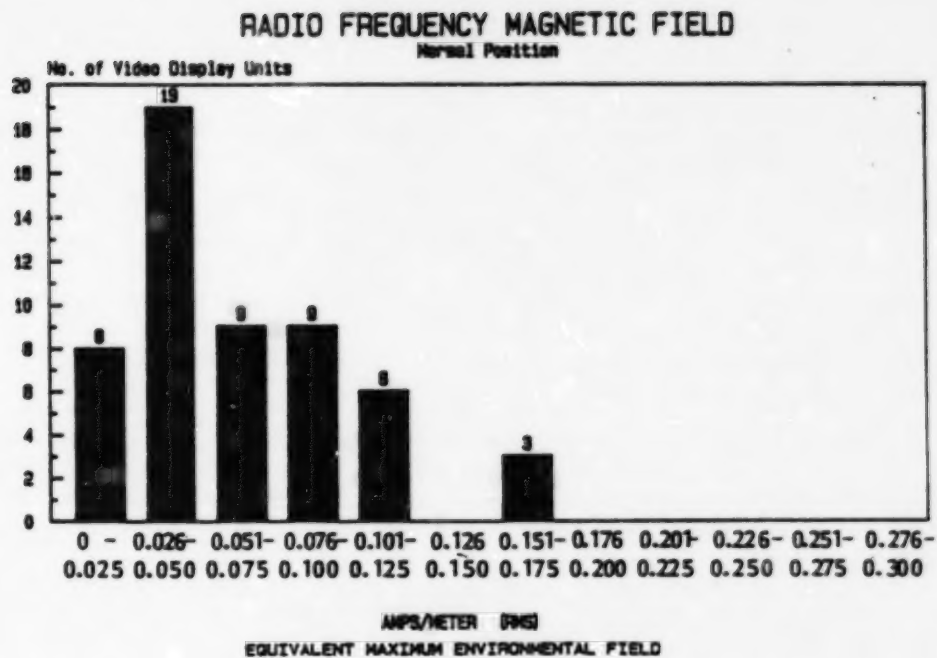


FIGURE 4
ENVIRONMENTAL 17kHz MAGNETIC FIELD-
NORMAL POSITION

REFERENCES

1. Characteristics of Low Frequency Electrostatic and Electromagnetic Fields Produced by Video Display Terminals. Ontario Hydro Research Division Report No 82-528-K.
2. Analysis of Operator Exposure to Electric Fields from Video Display Units. Ontario Hydro Research Division Report No 83-503-K.
3. Characterization of Low Frequency Magnetic Fields Produced by Video Display Units. Ontario Hydro Research Division Report No 83-504-K.
4. Investigation of Radiation Emissions From Video Display Terminals. Report 83-EHD-91. Department of National Health and Welfare, Ottawa. (1983)
5. An Evaluation of Radiation Emission From Video Display Terminals. Report FDA 81-8153. US Department of Health and Human Services, Bureau of Radiological Health, Rockville, Maryland. (1981)
6. Electromagnetic Compatibility Advisory Bulletin EMCAR1, Issue 2, Department of Communications, Government of Canada (1982).

APPENDIX A

PROCEDURE FOR SURVEYING VIDEO DISPLAY UNITS (VDU)

EQUIPMENT REQUIRED

1. E-field sensor and 6 ft coaxial cable
2. H-field sensor and special cable
3. Tripod for holding sensors
4. 610B electrometer
5. Chopper plate and grounding wire
6. 5103N scope with 5A22N plug-in
7. Camera and film
8. Measuring scale
9. Small sampling probe (portable E-field sensor)
10. Current probe

TEST METHOD

1. Plug in electrometer and scope.
2. Turn on VDU, electrometer and scope.
3. Allow to warm up for about 5 minutes. In the meantime fill out preliminary information on the data sheet (ie, date, unit tested, location, etc).
4. Place H-field sensor on tripod and locate at a 12" perpendicular distance from the CRT screen. Measure to centre.
5. Set 5103 scope as follows:
 - both inputs ungrounded
 - bandwidth 1 kHz (LF); 1 MHz (HF)
 - vertical deflection 1 mV/div
 - horizontal deflection 20 es/div
6. Connect sensor to + and - inputs.
7. Rotate sensor for maximum signal; change scale as necessary.
8. Photograph CRT display.
9. Record the following on the back of the film and on the data sheet:

- date
 - unit tested
 - H-field at 12", front
 - 20 e_s /div
 - vertical deflection factor
10. Remove H-field sensor, set up E-field sensor. Adjust tripod to locate the E-field sensor in the same location. Measure 12" to the backing foil.
 11. Set 5103 scope as follows:
 - -ve input grounded
 - bandwidth 1 kHz; 1 MHz
 - vertical deflection 10 mV/div
 - horizontal deflection 20 e_s /div
 12. Connect sensor to +ve input; change scale if necessary.
 13. Photograph CRT display.
 14. Record the following on the back of the film and on the data sheet:
 - date
 - unit tested
 - E-field at 12", front
 - 20 e_s /div
 - vertical deflection factor
 15. Record the approximate time that the VDU has been on (on data sheet).
 16. Set 610B electrometer to 30 V, centre zero, normal, locked.
 17. Without moving sensor, connect to electrometer input.
 18. Unlock meter and set to centre of scale.
 19. Block sensor with grounded plate and note magnitude and direction of meter deflection upon removal of grounding plate. Change scale if necessary.
 20. Repeat 2 to 3 times to verify reading. Record reading in + or - volts on back of previous picture and on the data sheet.
 21. Lock meter and disconnect sensor from electrometer.

22. Connect portable E-field sensor to scope and move around VDU maintaining 12" from case to find maximum signal. Change scale as necessary.
23. Replace portable sensor with the large E-field sensor at the maximum signal location.
24. With sensor at maximum position, photograph CRT display.
25. Record the following on the back of the film and on the data sheet:
 - date
 - unit tested
 - E-field at 12", actual location
 - 20 es/div
 - vertical deflection factor
26. Connect current probe connection to -ve input, set at 2 mA/mV. Connect probe to +ve input lead, positive input grounded.
27. Photograph CRT display.
28. Record the following on the back of the film and on the data sheet:
 - date
 - unit tested
 - current
 - 20 es/div
 - vertical deflection factor
29. Turn off scope and electrometer, return VDU to owners.
30. Put 4 photos in envelope with date, unit tested, and location of unit on outside.

APPENDIX B

VIDEO DISPLAY UNIT SURVEY OF ELECTROMAGNETIC FIELDS

Video Display Unit	Environmental Fields				
	Electrostatic Front (A) ¹ V/m	E _{rf} Front (A) ¹ V/m rms	E _{rf} Maximum (A) ¹ V/m rms	E _{rf} Maximum (B) ² V/m rms	H _{rf} Front A/m rms
1 Micom M2000	+10.5	2.40	14.40	4.64	0.093
2 Micom M2000	-3.8	0.80	0.80	ND	0.044
3 Micom M2000	+31.5	0.53	0.53	ND	0.086
4 Micom M2000	+14.3	0.51	0.51	ND	0.083
5 Micom M2001	+144.0	0.47	0.47	ND	0.040 ³
6 Micom M2001	-12.0	0.56	0.56	ND	0.045 ³
7 Micom M2001	-15.0	0.56	0.56	ND	0.048
8 Micom M2001	+3.0	0.47	0.47	ND	0.041 ³
9 Micom M2001	-18.0	0.53	0.53	ND	0.039 ³
10 IBM PC5150	+510.0	0.14	0.14	ND	0.038 ³
11 IBM PC5150	+495.0	0.30	1.20	0.44	0.046
12 IBM 3278-2	+5.1	0.06	0.06	ND	0.005
13 IBM 3278-2	+345.0	0.08	0.08	ND	0.005
14 IBM 8775	+8.3	0.63	0.63	0.16	0.160
15 IBM 3279	+11.3	0.60	0.60	0.16	0.157

Notes

- 1 Method A used to estimate environmental field.
 - 2 Method B used to estimate environmental field.
 - 3 Irregular waveform, rms values may be inaccurate.
 - 4 Actual frequency is approximately 22 kHz.
- ND Not detectable

VIDEO DISPLAY UNIT SURVEY OF ELECTROMAGNETIC FIELDS
(Continued)

Video Display Unit	Environmental Fields				
	Electrostatic Front (A) ¹ V/m	E _{rf} Front (A) ¹ V/m rms	E _{rf} Maximum (A) ¹ V/m rms	E _{rf} Maximum (B) ² V/m rms	H _{rf} Front A/m rms
16 Omron	-31.5	0.68	0.99	0.23	0.118
17 Omron	-22.5	0.60	0.83	0.51	0.160
18 Omron	-21.0	0.50	0.84	0.17	0.122
19 Omron 8035B	-90.0	0.75	1.23	ND	0.112
20 Omron 8035B	-12.8	0.51	0.89	0.28	0.106
21 Wang 5506-2	+105.0	0.36	0.36	ND	0.072
22 Wang	+405.0	0.48	0.48	ND	0.075
23 Wang 5506-2	+555.0	0.57	0.57	ND	0.064
24 Comterm S4270	-9.0	0.48	0.48	ND	0.059
25 Comterm S4270	+97.5	0.45	0.45	ND	0.066
26 Comterm S4270	+36.0	0.45	0.45	ND	0.054
27 Electrohome D01-402	+900.0	1.41	1.41	0.41	0.080
28 Electrohome D01-402	+1050.0	1.14	1.14	0.33	0.080
29 Electrohome Educator	+1500.0	2.10	2.10	0.46	0.033
30 Hewlett Packard 2647A	-1.5	0.44	0.44	0.23	0.025

Notes

- 1 Method A used to estimate environmental field.
 - 2 Method B used to estimate environmental field.
 - 3 Irregular waveform, rms values may be inaccurate.
 - 4 Actual frequency is approximately 22 kHz.
- ND Not detectable

VIDEO DISPLAY UNIT SURVEY OF ELECTROMAGNETIC FIELDS
(Continued)

		Environmental Fields				
Video Display Unit	Electrostatic Front (A) ¹ V/m	E _{rf} Front (A) ¹ V/m rms	E _{rf} Maximum (A) ¹ V/m rms	E _{rf} Maximum (B) ² V/m rms	H _{rf} Front A/m rms	
31 Hewlett Packard 2648A	-52.5	0.60	0.60	0.29	0.031	
32 Hewlett Packard 2648A	+15.0	0.45	0.45	0.21	0.023	
33 Sperry Univac 200	-8.3	0.11	0.11	ND	0.059	
34 Sperry Univac 20	+855.0	0.19 ⁴	0.53	0.23	0.033	
35 Sperry Univac 20	+840.0	0.08 ⁴	0.35	ND	0.024	
36 Radio Shack TRS80	+465.0	0.31	0.65	0.20	0.072	
37 Radio Shack TRS80	+615.0	0.25 ³	0.25	ND	0.019	
38 Nanotec XL-84	+1200.0	0.44	0.44	ND	0.032 ³	
39 Nanotec XL-84	+510.0	0.21	0.21	ND	0.015 ³	
40 Datapoint 8200	+405.0	0.75	0.75	0.46	0.041 ³	
41 Datapoint 8200	+225.0	0.81	1.35	0.70	0.038 ³	
42 AES	-8.3	2.07	10.80	3.60	0.096	
43 AES	-300.0	2.64	11.55	3.71	0.067	

Notes

- 1 Method A used to estimate environmental field.
 - 2 Method B used to estimate environmental field.
 - 3 Irregular waveform, rms values may be inaccurate.
 - 4 Actual frequency is approximately 22 kHz.
- ND Not detectable

VIDEO DISPLAY UNIT SURVEY OF ELECTROMAGNETIC FIELDS
(Continued)

Video Display Unit	Environmental Fields				
	Electrostatic Front (A) ¹ V/m	E _{rf} Front (A) ¹ V/m rms	E _{rf} Maximum (A) ¹ V/m rms	E _{rf} Maximum (B) ² V/m rms	H _{rf} Front A/m rms
44 Hazeltine	-60.0	0.75	3.0	1.14	0.088
45 Hazeltine	-165.0	0.87	3.18	1.25	0.102
46 Scan Edit II	+525.0	0.26	0.26	ND	0.038 ³
47 Scan Edit II	+285.0	0.21	0.21	ND	0.040 ³
48 Volker Craig VC404	+795.0	0.21	1.62	0.60	0.026
49 Volker Craig VC404	+855.0	0.17	2.34	0.93	0.037
50 Ramtek Datapath	+1350.0	0.13 ³	0.13 ³	ND	0.096
51 Ramtek Datapath	+195.0	0.16 ³	0.16 ³	ND	0.099
52 Digital VT52	-48.0	0.05	0.05	ND	0.042
53 Digital VT180	+720.0	0.25	2.46	0.93	0.106 ³
54 Tektronix	-5.3	ND	ND	ND	ND

Notes

- 1 Method A used to estimate environmental field.
 - 2 Method B used to estimate environmental field.
 - 3 Irregular waveform, rms values may be inaccurate.
 - 4 Actual frequency is approximately 22 kHz.
- ND Not detectable